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AQUATIC SYSTEMS IN THE MACKENZIE PORCUPINE DRAINAGES



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ECOLOGICAL STUDIES OF AQUATIC SYSTEMS
IN THE MACKENZIE-PORCUPINE DRAINAGES
IN RELATION TO PROPOSED PIPELINE
AND HIGHWAY DEVELOPMENTS

Volume 1

by

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1. SUMMARY

Plants and animals that live in rivers, streams and lakes (and the physical and chemical parameters that control their growth and reproduction) are being studied as indicators of aquatic ecosystem sensitivity to disruption by gas and oil pipelines, and road developments in the Mackenzie and Porcupine River Valleys. In 1971-72, Fisheries Research Board staff performed a broad chemical and biological survey to identify the different types of ecosystems and the species of organisms in this vast area. From these data, we selected three areas for more intensive study in 1972-75. These are: Fort Simpson area, being in the discontinuous permafrost region of the upper Mackenzie Valley lowlands; the Mackenzie Delta, a fertile and diverse labyrinth of lakes and channels; and the Porcupine River region west of Old Crow (Yukon), being a biologically unique glacial refugium and an area where local natives are largely dependent upon undisturbed seasonal movements of fish and other wildlife. Chemical laboratories, storage, and field H.Q. are at Yellowknife, and chemical and biological laboratories in the Freshwater Institute are utilized.

The results of our survey work in the study area indicated: 1) naturally turbid, silt-laden rivers and lakes supported a less abundant and diversified invertebrate fauna and flora than did aquatic systems with low concentrations of suspended sediment, 2) there was a decline in abundance and diversity of benthic invertebrates with increasing latitude, 3) that water solution ionic strengths varied from extremely dilute (30 umhos/cm at 25°C) to nearly full strength sea water, 4) that suspended sediment concentrations varied from less than 1g m^{-3} to over $2,000\text{g m}^{-3}$, and 5) that bottom sediments in rivers, streams and lakes varied from clay-size to boulder and clean bedrock substrates, with a variety of types of organic matter in the sediment. Natural events related to hydrological cycles and terrain instability caused great fluctuations in the physical and chemical characteristics of water bodies, and their flora and fauna.

To predict the effects of corridor¹ (pipelines and road) development, we have performed controlled experiments in which crude oil was added to a stream in the northern Yukon and a small lake in the Mackenzie Delta. In the Fort Simpson and Inuvik regions, we have utilized disturbances from recent construction of the Mackenzie Highway across stream watersheds as experiments to determine the effects of increased siltation on aquatic ecosystems. Laboratory experimental studies on interactions of oil, silt, dispersing agents, and microbial degradation rates of petroleum products are underway. We have also visited sites of accidental oil spills in Inuvik, Resolute Bay, and Yellowknife Bay to assess the impact of the oil and clean-up activities on aquatic ecosystems. Experimental studies on the effects of increased siltation on lakes and streams are just beginning.

¹ The term "corridor" is used in this report to represent the general location of possible pipeline routes, but it is recognized that no corridor per se has yet been recognized or approved.

Although our studies are still in progress, we have the following tentative conclusions and recommendations: 1) Increased siltation in a river or lake generally results in decreased abundance and diversity of aquatic organisms. Silt loads in streams will increase during and after construction activities in watersheds. 2) Clear, low-velocity rivers in unstable terrain, and areas where springs occur, should be avoided by corridor development. 3) The effects of crude oil in streams and lakes are rapid (within hours) and often lethal to many aquatic organisms. 4) Existing oil spill contingency plans are not adequate to prevent or even reduce ecosystem disruption. It will be necessary to contain the inevitably spilled oil in a small area to facilitate clean-up and to reduce environmental changes. In streams and rivers, this will be very difficult, and will require the development of new techniques. 5) Bridges are preferred over culverted road crossings in all but the smallest streams. The area of the right of way, and the number of cleared crossing sites (i.e. temporary crossings) should be kept to a minimum. 6) The rate of recovery of oil or silt disturbed aquatic ecosystems is unknown and requires long (5 year) term studies.

ECOLOGICAL STUDIES OF AQUATIC SYSTEMS
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AND HIGHWAY DEVELOPMENTS

2. INTRODUCTION

2.1. General Nature and Scope of our Study

The Freshwater Institute of the Fisheries Research Board of Canada undertook in 1971 a study of the impact of northern development (gas and oil pipeline, highway construction and operation) on freshwater ecosystems of the Mackenzie and Porcupine River Watersheds. Our first activity was to conduct a general survey of the distribution and abundance of aquatic organisms in this vast and biologically poorly known region (see Appendix I). Benthic organisms are of fundamental importance with respect to food-chain inter-relationships of aquatic ecosystems; their utilization by indigenous fish species is summarized in Appendix VI. Also by nature of their diversity, they are likely to provide indicator species in any study of the impact of pipeline disturbance on these ecosystems. Selected physical and chemical parameters that control the growth and reproduction of these aquatic organisms were also measured. The region covered in this study was immense, i.e., lengths of 1600 km of Mackenzie River and Delta, and over 560 km of watersheds from the Richardson Mountains to the Northern Yukon-Alaska border. This survey data is included in appendices, and represents the beginning of an inventory of part of our aquatic resources in these diverse and rich habitats. It may also serve as a beginning of a baseline data bank on the natural state of these aquatic ecosystems. There are far too many areas in the North where disturbances have occurred and no pre-disturbance baseline data exists.

From these general and incomplete data, we have selected three geographic areas for intensive study, (Appendix I): the Fort Simpson area, being in the discontinuous permafrost region of the upper Mackenzie Valley lowlands; the Mackenzie Delta, a fertile and diverse labyrinth of lakes and channels; and the Porcupine River region around Old Crow Settlement, being a glacial refugium where local natives are largely dependent upon undisturbed seasonal movements of fish and other wildlife. Chemical laboratories, storage, and field headquarters are in Yellowknife, and chemical and biological laboratories in the Freshwater Institute are heavily utilized. Our studies in these areas are designed to obtain detailed information on the ecology of aquatic organisms in their undisturbed habitat. These studies will enable us to relate the natural variation of the ecosystem to natural stresses from the environment. These studies also enable us to design experiments to test the sensitivity of aquatic ecosystems to disturbances likely to occur during and after corridor development.

We have three such experiments in progress now: crude oil was added to a small stream in the Yukon and to a small Mackenzie Delta lake. In addition to these controlled experiments, we have utilized Mackenzie Highway construction disturbances in watersheds of the Fort Simpson and Inuvik regions as experiments to determine the effects of increased siltation on aquatic ecosystems. The results of these experiments, if carefully monitored for sufficient time, will allow us to predict the impact of similar activities in regions of similar geography and climate. This experimental whole ecosystem approach to corridor impact studies will be expanded to cover toxic and deleterious substances used or created in the construction and operation of corridor functions.

2.2. Objectives of our present study

2.2.1. To assess the effect of increased silt loads on the aquatic ecology of rivers, streams and lakes. Experimental and observational data to meet this objective are from 1) studies on the effect of the Mackenzie Highway crossing of the Martin River, near Fort Simpson, 2) observations on the effect of a landslide on the biota of Caribou Bar Creek in Northern Yukon, and 3) observations on Mackenzie Delta lakes that receive varying amounts of silt from annual spring floods.

2.2.2. To assess the effect of crude oil on the aquatic ecology of rivers, streams, and lakes. Experimental and observational data to meet this objective are from 1) a controlled oil spill on Caribou Bar Creek in the Northern Yukon, 2) a controlled oil spill on a Mackenzie Delta Lake, 3) studies on the rates of benthos colonization and rates of oil loss from standardized artificial oiled and non-oiled substrates, and 4) studies on an accidental oil spill in Yellowknife Bay.

2.2.3. To assess the distribution, abundance and diversity of aquatic organisms (primarily zoobenthos) which occur in regions subject to present or future corridor development. These studies are being carried out at the three field camps in order to utilize our experimental results (see above) in a predictive manner. To make successful predictions concerning the fate of benthic organisms after disturbance, it was considered necessary to acquire ecological information of a general nature.

2.2.4. To assess the range of natural and man-induced variation in physical and chemical parameters that influence the growth of aquatic organisms. This activity is being done in the three field camps, with special attention being given to the determination of rates of transport of suspended and dissolved materials from representative watersheds.

2.3. Relation of our Study to Pipeline and Highway Development.

Construction activities of any sort on permafrost and discontinuous permafrost terrain cause increased erosion, chiefly due to disturbance of the thermal balance of vegetation and soil. The resulting increase in the rate of supply of vegetation debris, soil, and water to streams and rivers will have an effect upon the habitat of aquatic organisms. The severity and duration of this effect are being studied, and attempts are being made to estimate the natural rates of supply of particulate and dissolved material to rivers, streams and lakes. The severity of the disturbance will be adequately monitored in our experimental studies, but the recovery time of the ecosystem will require continued careful study. At stream crossings, the bank and bed material of the stream will be disturbed repeatedly, and ice bridges, culvert installation and bridge construction will create physical and chemical changes in the ecosystem. The main effect of these types of disturbances will be 1) alteration of the stream bed i.e., the substrate that benthic organisms and fish depend upon for feeding, growth and reproduction, 2) the alteration of the proportion of organic and inorganic material in suspension in the water, i.e., the proportion of food material to non-food material, and 3) the reduction of light transmission through the water, resulting in reduced growth of attached algae and higher plants. Our work will give information concerning which areas are to be set aside for special protection and/or preservation. In some cases, our studies will predict what seasons of the year are especially sensitive to various types of disturbances.

During and after construction activities in the corridor, many products and waste materials of man and industry will enter these watersheds. It is quite easy to list over a hundred toxic or deleterious substances that will be brought into the Mackenzie-Porcupine River watersheds during construction and operation phases of corridor development: some examples would be crude oil, high temperature lubricating oils, pesticides, anti-corrosion paints, pipe-cleaning and welding materials, human and machine wastes, including combustion products and treated and untreated sewage. Of these substances, we have some knowledge of the effect of crude oil and nutrients from sewage, and we find that existing plans for the control of these materials will result in deleterious effects upon the ecosystems that we have studied. Our studies will define the possible changes and enable suggestions as to how to avoid unnecessary disturbances.

Healthy aquatic ecosystems will have increasing importance in respect to domestic or commercial fisheries, recreation, tourism, and the "perceptive needs of man" in the sense of Naysmith (1971). Our goals are to provide advice on how to reduce the degree of unnecessary disturbance to aquatic ecosystems.

3. RESUME OF CURRENT STATE OF KNOWLEDGE

3.1. Physical and Chemical Literature

Hitchon et al. (1969), Levinson et al. (1969), Reeder et al. (1972), Thomas (1957), and Brandon (1965) give some information on the solution chemistry of surface and subsurface waters in the Mackenzie and Porcupine River Valleys. MacKay (1972, 1970, 1966) and Krouse and MacKay (1971) describe the lack of mixing of Mackenzie waters with Liard and Great Bear River waters. Hitchon and Krouse (1972) have studied the stable isotopes of oxygen, carbon, and sulfur in the Mackenzie watershed, and found that biogenic processes affected the stable isotope ratios of carbon and sulfur. Data on discharge for Mackenzie and Porcupine drainages can be found in the annual series of publications by Water Survey of Canada (1970 for example) and in Clark and Peterson (1972). Oceanographic data on the Mackenzie Delta and adjacent Beaufort Sea is given in Barber (1968), Healey (1970), Kelly (1967) and Cameron (1953), being primarily information on salinity, temperature and currents.

Suspended sediment data is lacking for NWT and Yukon rivers, although Water Survey began these measurements on selected Mackenzie stations in 1972 using the approach described in Stichling and Smith (1968). Dewis et al. (1972) have studied the relationship between trace element concentrations in sediments and the nature of Mackenzie drainage sediments. Gill (1972) and MacKay (1963) have studied sediment movements in the Mackenzie Delta. Johnston and Brown (1961, 1964, 1965) give information on the sedimentary stratigraphy of the Delta, and show the effect of a Delta Lake on the distribution of permafrost under and adjacent to the lake. Since solution and suspended sediment chemistry are greatly dependent on the source materials in weathering, we have consulted Craig and Fyles (1960), Tassonyi (1969), Hughes (1972) and others for glacial history and geology of this area. Naidu et al. (1971) give mineralogic and particle size data on Beaufort Sea sediments. MacKay (1972) and MacKay, Rampton and Fyles (1972) studied permafrost and ground ice in the lower Mackenzie Valley, Delta and Beaufort Sea. Many other references of pertinence to our work are found in the general bibliographies of the Mackenzie Delta (Jones, 1969) and Roberts-Pichette (1972).

General references that are useful to consult for comparison with Mackenzie-Porcupine watershed chemical data are Livingstone (1963, for solution chemistry of the world's rivers) and Holeman (1968, for suspended sediment rates of transport for the world's rivers). Wolman (1971), Cleaves et al. (1970), and Judson (1968) give examples of the effect of watershed disturbance on suspended sediment loads in rivers and streams in temperate latitudes. Leopold et al. (1964) and Scheidegger (1970) give general and theoretical accounts of river mechanics and sediment transport. It should be stressed that it is difficult to use much of the existing literature in comparisons, since so little of the literature deals with Arctic and Sub-Arctic systems.

3.2. Biological Literature

General treatments of the ecology of freshwater systems are to be found in such texts as Hynes (1970), Reid (1961), Ruttner (1966), and Hutchinson (1957, 1967). Specific and detailed knowledge of the aquatic invertebrate

fauna of the arctic is very scanty. Taxonomic contributions occur in the Report of the Canadian Arctic Expedition, 1913-18, the Report of the Alaska Harriman Expedition, the Meddelelser om Grønland and more recently from the Symposium on the Distribution of Arctic and Subarctic Insects (1958). Ecological contributions have appeared mainly after World War II. These were reviewed by Livingstone (1966) who showed that greater attention was paid to the physical and chemical limnology of arctic lakes, while less work was done on biological limnology (zooplankton life histories by Comita (1956), Edmondson (1955), McLaren (1961, 1969a); studies on phytoplankton and benthos by Livingstone (1966), Kalff (1967, 1970, 1971), McLaren (1967a and b, 1969b). Probably the most concentrated effort on biological research has come from two projects: the IBP Char Lake Project on Cornwallis Island, and the Hazen Camp on Ellesmere Island. The Char Lake studies concerned the biology of chironomids (Welch, 1971), the ecology of zooplankton (Lasenby and Langford, 1972; Roff and Carter, 1972), the ecology of streams at Char Lake with emphasis on the benthos (Stocker, MS 1972), seasonal cycles of phytoplankton and photosynthetic pigments (Kalff, Welch, and Holmgren, 1972), and bacterial dynamics (Morgan and Kalff, 1972). The Hazen Camp project has produced studies on the biology of chironomids and their environment. (Danks and Oliver, 1972a and b; Danks, 1971a and b; and Oliver 1963, 1964 and Oliver and Corbet, 1966). This project has also generated ideas on the adaptations of arctic insects to their environment (Downes, 1962, 1964 and 1965).

The literature on the effects of silt in aquatic ecosystems of the Temperate Zone is more diverse. Patrick (in Mackenthum and Ingram, 1964; p. 137) discussed pollution by suspended and deposited sediments. Not only is sediment (from accelerated erosion of poorly managed watersheds) the greatest pollutant of waters in terms of volume (Wolman, 1972), but it also may carry other pollutants such as fertilizers, pesticides, radionuclides, and toxic materials and transport them over great distances (Guy and Ferguson, 1970; Robinson, 1971. See also Kelley, in Eldridge and Wilson, 1959; and Foess, 1972). Sediment rich in organic matter is often more harmful to benthic organisms in aquatic environments than inorganic sediments (Guy and Ferguson, 1970).

Causes and sources of increased sedimentation in aquatic ecosystems can be natural or man-made and have been summarized in tabular form by Bullard (in Eldridge and Wilson, 1959) and by Guy and Ferguson (1970). Cordone and Kelley (1961) stated that increased erosion often results in widespread and permanent damage to aquatic systems. Robinson (1971) stated that agriculture, streambank erosion, and construction activities were great contributors of sediment to streams. "Unlike the continuing erosion on agricultural lands not checked by soil conservation practices, construction sites erode mainly during the brief periods between land clearing, shaping and stabilization of the new surface. However, the sediment released may have a lasting effect on the channel shape as well as the aquatic environments downstream" (Guy and Ferguson, 1970; p. 217). Further, Bullard (in Eldridge and Wilson, 1959) indicated that the time lapse between road construction and restabilization of the disturbed terrain resulted in significant siltation in streams.

Necessary to an understanding of the effects of sedimentation on the biota of waterways is a knowledge of river hydraulics. Einstein (1972) reviewed the sedimentation aspects of river hydraulics. Additional discussions of the principles of sediment transport can be found in Guy and Ferguson (1970),

Krygier, Brown, and Klingeman (1971), and Foess (1972). Cordone and Kelley (1961) reviewed the influences of sediment on physical and chemical parameters of waters. Wickett (in Eldridge and Wilson, 1959) and Cummins and Lauff (1969) provided sediment grade scales to define their usages of sediment-related terms.

The effects of deforestation (mainly logging), road building, mining, dredging, and gravel pit operations on stream sediments are discussed by Tebo (1955), Bullard (in Eldridge and Wilson, 1959), Chapman (1962), Krygier et al. (1971), Burns (1970, 1972), Alaska (1972), Hauck (in Eldridge and Wilson, 1959), Wagner (in Eldridge and Wilson, 1959), and Gammon (1970), Alaska (1972), and Burns (1972).

Reviews of the effects of sedimentation on aquatic biota were presented by Cordone and Kelley (1961), and Hynes (1966, 1970). Effects of suspended and deposited sediments on green plants, fish, and macroinvertebrates, in addition to those discussed in the above reviews, are in Phinney (in Eldridge and Wilson, 1959), Chapman (1962), and Mackenthun and Ingram (1964); Wickett (in Eldridge and Wilson, 1959), Hamilton (1961), Chapman (1962), Sheridan and McNeil (1968), Gammon (1970), and Burns (1972); and Kelley (in Eldridge and Wilson, 1959), Hamilton (1961), Mackenthun and Ingram (1964), Chutter (1969), Cummins and Lauf (1969), Gammon (1970), and Mackenthun and Keup (1972), Nuttall (1972 and Burns (1972) respectively.

Not all the effects of increased sedimentation are detrimental to ecosystems. For example, Robinson (1971) noted that sediments can prevent eutrophication in nutrient-rich waters by absorbing nutrients from the solution phase. Hamilton (1961) reported that bottom fauna was unaltered by the presence of sand and silt in suspension originating from the washings of a gravel pit (but his measurements of suspended sediments were not quantitative). In general, adult fishes are not affected by sedimentation (Hamilton, 1961; Cordone and Kelley, 1961; and Hynes, 1966). However, the majority of the effects of sedimentation are not beneficial. Cordone and Kelley (1961) and Hynes (1966) stated that fish spawning and development are drastically affected by sedimentation. Cordone and Kelley (1961) indicated that increased sediment loads on streams had a deleterious effect on bottom fauna, and that this reduction in bottom fauna abundances and diversity adversely affected salmonid fish populations.

The increasing frequency of disastrous oil spills has given impetus to the study of the effects of this kind of pollution on the environment. The description and immediate effects of four major spills have been documented; the tanker 'Arrow' in Chedabucto Bay (Task force operation oil, 1970); the tanker 'Torrey Canyon' in the English Channel (Smith, 1968); the Santa Barbara spill (Foster et al., 1971); Holmes, 1969) and the West Falmouth spill (Blumer, 1972; Sanders et al., 1972). These disasters all occurred in the marine environment. Very few major oil-spills have occurred which have affected bodies of fresh water. The only one in Canada for which documentation is available was the Athabasca River oil sands spill (Alberta Government Report, 1970).

Most of the oil spill literature to date is of a descriptive nature but sufficient time has now elapsed since the four marine spills mentioned above for some in-depth studies to be completed. There are now several bibliographies for this rapidly expanding field (e.g., Moulder and Varley, 1971). In addition review articles are now beginning to appear in the literature (Nelson-Smith, 1970).

Most major fractions of crude oil are known or are suspected to have varying levels of toxicity to living organisms in the long or short terms. The aromatic hydrocarbons represent the most dangerous fraction: the low boiling point components (e.g., benzene, toluene, xylene etc.) are acute toxins for all living systems (Blumer, 1969). These compounds are probably responsible for the immediate mortality of aquatic organisms after oil spills. These compounds may represent as much as 80% of the aromatic fraction of gas condensate (Hitchon and Gawlak, 1972). After these low boiling fractions have evaporated (~2 days), the residues probably represent a less toxic hazard to organisms although their adverse effects may then be primarily physical in nature (e.g. clogging respiratory surfaces etc.) or be long term in their biochemical effects.

In the marine environment, littoral organisms are the group most adversely affected (Carthy and Arthur, 1968; Smith, 1968; Woodin et al., 1972). In most cases there is evidence of recolonization within six months of being subjected to oil or gasoline (Woodin et al., 1972), although in some cases not all taxa recolonize in four times this length of time (Bugbee and Walter, 1972).

The sensitivity to oil pollution of various organisms covers a wide range. Crustaceans are amongst the most sensitive forms (Smith, 1968) and of these, amphipods are probably the best indicators of marine oil pollution (Blumer, 1972; Kasymov and Granovskiy, 1971). These animals are also amongst the least tolerant to oil pollution in freshwater (McCauley, 1966). Several species of aquatic organisms actually ingest the oil residues, after evaporation of the more toxic components, and actually assist in oil removal by cleaning surfaces and passing it through their alimentary tracts. This was found to be the case with limpets (Smith, 1968), freshwater bivalves and gastropods (Jahn, 1972) and zooplankton (Conover, 1971).

The effect of oil on higher plants (primarily terrestrial) has been studied by Baker (1970). McCauley (1966) reported that oil was markedly toxic to plankton as well as to the sediment macrofauna. In her study it was significant to note that substantial numbers of both planktonic and benthic organisms were tolerant to the presence of oil in this fluviatile habitat. The tolerant zoobenthic taxa included forms which are characteristic of oxygen-depleted habitats (Oligochaeta, Chironomidae, Nematoda and leeches).

Two studies of the effect of oil on phytoplankton productivity in the Arctic both showed that algal growth was reduced by 90% in one case (Dickman, 1971) and 50% in the other (Alexander et al., 1972) when the algal population was exposed to oil.

Hydrocarbons are known to be involved in the reception of chemical stimuli by organisms in aquatic habitats. Such stimuli are important for purposes

of food and mate location, escape from predators, habitat selection and homing ability of aquatic organisms. The presence of oil may affect all these activities in the life-history of aquatic organisms by blocking receptor sites or mimicking natural stimuli (Blumer, 1969). In this regard, hydrocarbons are known to inhibit the chemoreceptive ability of marine bacteria (Mitchell et al., 1972). These authors also discuss the implications of this phenomenon in a broader ecological context.

The biodegradability of three northern crude oils (Prudhoe Bay, Atkinson Point and Norman Wells) by microorganisms was investigated by Westlake and Cook (1972). The Norman Wells crude oil was most readily degraded and the Atkinson Point oil was the least susceptible to microbial decomposition with Prudhoe Bay oil occupying an intermediate position in this respect. Atkinson Point crude represents the worst potential hazard to biological systems, since it contains the highest proportion of the most toxic fractions (aromatics) and the residues most resistant to breakdown (asphaltenes). This type of oil is therefore likely to have the longest persistence in an arctic ecosystem as well as the maximum immediate adverse effect.

Many of the studies on the behaviour of crude oil in Arctic systems are concerned with the effect of climate (temperature and ice) on the physical properties of the oil (e.g. Glaeser and Vance, 1971). Considerable effort is also being expended on the clean up of oil spills in this and more temperate environments (Barber, 1970; Hoult, 1969 and Vance, 1971).

4. STUDY AREAS

4.1. The Fort Simpson region (Appendix I, Fig. 1) is in the upper Mackenzie Valley lowlands, and covers the area roughly between Trout and Willowlake River. The region is generally characterized by relatively low-relief terrain composed of alluvial, lacustrine, glaciofluvial, and eolian surficial sediments. The area is underlain by Devonian limestones and shales (Douglas, 1968).

The deposition of lacustrine sediments by glacial lake McConnell in this area is described by Craig (1965). Day (1966, 1968) and Crampton (1972) describe the soils and vegetation in this area. Discontinuous permafrost is encountered in this area, and permanent ice is most extensive in areas of silty lacustrine deposits (Brown, 1970, Crampton, 1972).

The Liard and Mackenzie Rivers dominate the area by their magnitude, and have steep banks (10-40 meters high) of fine alluvial sediments. The Mackenzie River, above the confluence of the Liard River, is predominately Great Slave Lake outflow, and is relatively low in suspended sediment. The Liard River is extremely turbid, and contributes to the turbid water mass on the southwest and west bank of the Mackenzie River for approximately 1000 km (MacKay 1966, 1970; Krouse and MacKay 1971). During and after high water levels, the Mackenzie and Liard deposit silt along their stone-paved banks, and in the mouths of smaller tributaries. A vast amount of terrestrial vegetation debris is carried by these rivers.

The smaller tributaries of the region are humic acid colored, shallow (<1m in depth), usually low in suspended sediments, and have clean boulder-cobble sediments. These streams are usually in a sharp narrow valley with 5-20 meter high banks of silt, sand and gravel. Local exposure, vegetation, and active layer thickness influence these streams greatly, especially in summer and fall. The relative abundance of deciduous trees (aspen, poplar, birch) in this area contributes to stream metabolism in the Fall, whereas this source of nutrients (leaves) is less important further North.

Local people (in Jean Marie, Fort Simpson, Wrigley Settlements) utilize aquatic resources for food (whitefish, grayling, pike) and recreation. With the advent of the Mackenzie Highway reaching Fort Simpson and further construction North in 1972, this area will be increasingly important for tourism, recreation, and sport fishing.

4.2. The history, geography, climatology, hydrology and vegetation of the Mackenzie Delta has been summarized by Mackay (1963) and Day and Rice (1964). This region, from Point Separation in the Mackenzie River mouth to seawater in Mackenzie Bay and Kugmallit Bay, covers some 12,000 km² of sinuous channels, myriads of floodplain lakes, and floodplain Boreal forest (Appendix I, Fig. 2). There is little tidal range and minimal wave action within the Delta, since water levels are controlled by the discharge of the Mackenzie River. The modern delta consists mainly of the Richards Island area, while the Tuktoyaktuk Peninsula was built of glacial moraine and outwash, and thermokarst deposits (Rampton, 1972).

The region has been glaciated, with the exception of the Tuk Peninsula east of Mason River (Mackay, 1963; Hughes, 1972; Rampton, 1972). Permafrost occurs throughout the entire area from Point Separation into the Beaufort Sea (Mackay, 1973), with the depth of the active layer depending upon its proximity to

freshwater and vegetation cover. Johnston and Brown (1965) have shown that the depth of unfrozen sediment near and under Mackenzie Delta lakes is very great.

There are three main channels in this Delta: West (Peel) Channel, Main Channel, and East Channel. Discharge from the Mackenzie ($2300 \text{ m}^3 \text{ sec}^{-1}$ in winter, over $28,300 \text{ m}^3 \text{ sec}^{-1}$ during break-up) flows mostly through the Main Channel (67%), and the rest is equally divided between the East and West Channels (MacKay, 1963). The West channel receives most of its water from the Peel River, and a little from the Mackenzie, via the Main and Aklavik channels, and empties into Shallow Bay. The Main channel has its primary discharge near Kendall Island, but distributes water to Shallow Bay and the East channel via Reindeer and Oniak channels respectively. The East channel arises from the Main channel north of Point Separation, flows along the Caribou Hills and discharges into the Beaufort Sea via Kugmallit Bay, having received some Main channel water north of Inuvik. For a more thorough discussion of these, and other features relating to the physical geography of the area see Mackay (1963) and D.K. Mackay (1973).

During flood stages, most of the Delta is covered with silt-laden Mackenzie water. Many of the lakes between and south of Inuvik and Aklavik are more permanent, however, and appear to be less affected by inundation of silt from the Mackenzie. These lakes are less turbid, and have a higher biomass of aquatic plants and animals. A year-round local fishery is supported by the Delta, the economically important fish being whitefish (broad, humpback, her-ring, inconnu), but pike and burbot (losche, *Lota lota*) are also taken. People from the settlements of Arctic Red River, Aklavik, Fort McPherson, Inuvik, and Tuk utilize these resources. Muskrat and beaver live off the luxuriant aquatic macrophytes of Delta lakes, and are important in the economy of the local people.

4.3. The Western Porcupine and Old Crow River region (Appendix I, Fig. 1) is characterized by cotton grass, sedges, tussocky dwarf spruce uplands, and white spruce forested floodplain lowlands (Zoltai and Pettapiece, 1973). Local relief is greater than 300 m in this area. The hydrology and surficial geology of this area is partly the result of the drainage of a glacial lake in the region of the Old Crow Flats, and the diversion of Bell River Watershed from the Peel to the Porcupine River basin. The Porcupine and its Western tributaries are deeply incised through fine, organic lacustrine sediments, alluvium, and the prevailing bedrock, (granites, metamorphosed sediments, quartzite, limestone, dolomite, sandstone, and chert), and have high (20-60 m) steep banks in many areas (Hughes, 1972). Permafrost occurs throughout the area. Complex soils are developed on poorly drained hummocky terrain (Zoltai and Pettapiece, 1973). The Old Crow and Western Porcupine region was not glaciated, and was possibly a zoogeographic refugium during glaciation. The zoogeographic distribution of fish and benthic organisms, and their relation to Mackenzie, North Slope, and Pacific faunas, is of great scientific interest (Lindsey and McPhail, 1970; and personal communication, 1973). It is likely that man has been utilizing these aquatic resources for 30,000 years (Irving and Harrington, 1973). Rivers from this area generally have three regions of biological significance: the alpine creeks or headwaters, foot-hill streams, and large meandering floodplain rivers. These habitats, often within the same watershed, have different physical and chemical characteristics, different velocities and substrates and correspondingly different biological communities. Local people of the area (Old Crow Settlement) utilize

aquatic resources, largely king, silver and chum Salmon, but whitefish, grayling and pike are also taken. Muskrat, an aquatic mammal which uses aquatic vegetation for food, is important in the economy of these people (Naysmith, 1971).

4.4. The above mentioned areas are being studied in detail, since they represent three distinct ecological areas. Regions of the Mackenzie Valley and Northern Yukon not included in these study areas were surveyed in 1971-72, and in some cases are being less intensively studied presently. We are sampling at most Water Survey discharge stations throughout the Mackenzie Valley. These stations are identified and briefly described in Water Survey of Canada (1970). These stations are being monitored to enable us to evaluate the extremes of sediment and dissolved element erosion rates in a greater variety of watershed types.

4.5. Our study is designed to answer two questions (see 2.2. Objectives): What is the effect of increased siltation on aquatic ecosystems of the Mackenzie-Porcupine watershed rivers and lakes, and what is the effect of oil and oil industry by-products on these ecosystems? To accomplish this, we are studying the natural life cycles of aquatic organisms and the physical and chemical parameters that influence their growth and reproduction. This is necessary knowledge for the design of experimental studies to directly test the effect of the above mentioned disturbances.

This study gives data on our efforts to identify the species of aquatic organisms and their seasonal variation in abundance. To accomplish this, we have directly sampled the organisms living on the bottoms of rivers and lakes, in the water column, and those that emerge from the water to reproduce on land or in the air. The seasonal variation in the various life cycles of these organisms requires year-round studies to delineate the times in the year of greatest susceptibility to disturbance. We report the abundance of organisms living on a unit area of stream substrate, organisms moving into or out of a cross sectional area of a stream (termed "drift"), and organisms emerging from the water to the air. These studies have revealed great variations in the natural abundance and diversity of aquatic organisms, which is essential information for the proper evaluation of disturbances due to corridor development, and for the interpretation of experimental tests of the effects of pipeline and road construction operation.

The natural rates of supply of nutrient elements, food materials, suspended and dissolved matter, are being studied in our selected study areas. Water temperature, turbidity and light penetration, velocity and discharge, salinity, and stream (or lake) sediments are some of the parameters being followed through the seasons to ascertain their importance to the growth and reproduction of aquatic organisms.

Based on our available and continuing studies of the natural states of these ecosystems, we have designed and executed experiments to directly test two likely effects of pipeline and road development, i.e. increased siltation and oil spills. In Caribou Bar Creek (Northern Yukon), where we have background and contemporary control data, we added crude oil to a stream. We added crude oil to a small Mackenzie Delta lake, for which background and control data are recorded. The construction of the Mackenzie Highway through the watershed of the Martin River (near Fort Simpson) provided us with an experiment on the

effect of watershed disturbance. A natural landslide on Caribou Bar Creek enabled another experiment on the effect of increased silt loads in the stream to be monitored. In addition, we have experimentally placed crude oil-coated stream substrates (in wire baskets) in streams, rivers, and channels of the Fort Simpson, Mackenzie Delta, and Porcupine River regions. The colonization of these oil-coated substrates by aquatic organisms is compared to natural substrates, and estimates of the rate of loss of oil on the substrates can be obtained.

The broad route of the pipeline-road corridor includes a great variety of habitats within the ecosystems under study. The parameters and resulting data from the three intensively studied areas probably cover the extreme range found along the corridor. Faunal assemblages and specific physical and chemical data cannot be firmly predicted throughout the entire area, but the impact of corridor development can be roughly estimated from our present study. This predictive capacity is largely based on our experimental approach to corridor development environmental studies. The validity of our experimental work is dependent on our understanding of the natural ecosystem in selected areas that are representative of the route of the corridor.

5. METHODS

5.1. Physical and Chemical Methods

A detailed account of our field and laboratory methods is given in Appendix VII. A simplified summary of these techniques is given in Table I. We used comparable sampling equipment in all localities. The field laboratory equipment was supplied, standardized, and serviced from Yellowknife. Water samples were filtered and the filtrate acidified in field camps within hours of collection. Determinations of pH, HCO_3 , specific conductance, oxygen, turbidity were made in situ or within hours of collection. Suspended sediment samples were taken with depth-integrating U.S.G.S. sampling gear, or by handfilling a plastic bottle from the surface.

Sample shipment from remote localities was accomplished through chartered or commercial aircraft. Samples from Fort Simpson, Inuvik, Old Crow and other regions usually reached Yellowknife within a week to ten days of the sampling time. In Yellowknife, analyses for suspended sediment, total dissolved nitrogen, total dissolved phosphorus, particulate phosphorus, silica, chloride, sulfate and chlorophyll were done.

Field-filtered, acidified filtrates, and centrifuged sediment were shipped to Winnipeg for analyses of Ca, Mg, Na, K, Fe, Mn, Pb, Zn, Cu, Al, Cd and other determinations (see Appendix VII).

5.2. Zoobenthos Sampling Methods

A detailed account of the field and laboratory methods used is given in Appendix VII. A simplified summary of these techniques is given in Tables II and III. These methods were used throughout the zoobenthos programme, although special procedures and sampling sequences were used in the experimental studies. (See Appendix VII, Section 1.3.).

The 1971 open-water season was used primarily to survey the study area and consequently many of the sampling methods employed were only qualitative. An evaluation of sampling technology with respect to the habitats studied was also carried out at this time. As a result, it was possible in 1972 to use refined quantitative methods.

The quantitative sampling gear consisted of existing or modified stream and lake sampling apparatus chosen with a view to their efficiency and repeatability over successive sampling seasons in the various habitats in which they were employed. Zoobenthos was sampled primarily by the use of grabs, Surber samplers and artificial substrates. Drift organisms were sampled by drift-nets and emergence traps were used to collect adult insects.

Flowing water habitats were usually sampled along a three-station transect, one station being in mid-stream, the other two in lateral locations.

Samples were sieved through a 200 μm mesh screen and sorted as soon as possible after collection. When time constraints did not allow live sorting, the samples were preserved in formalin and sorted at a later date. Sorting was accomplished with the aid of magnifying illuminators and binocular microscopes.

Most samples were pre-sorted in the field-camps, and specimens were preserved in 70 - 80% ethanol and shipped to the Winnipeg laboratory for further processing.

Table I Summary of Physical and Chemical Sampling and Analysis Methods for Mackenzie-Porcupine Watershed Study, 1971-73. For details and references, see Appendix VII

Parameter	Units	Field Sampling and/or Measurement	Laboratory Measurement Technique
Temperature	°C	YSI thermistor	
Turbidity	%T, meters	Hydroproducts Transmissometer, Secchi disc	
Suspended Sediments (Seston)	gm ⁻³	US-D-49, US-DH-59 US-DH-48 depth-integrating samplers	centrifugation, filtration, and gravimetric determination of weight per unit volume.
Bottom Sediments	- -	Lane buckets, Ponar, Ekman, Peterson grab samplers.	Particle size determination by sieves and sedimentation rates in water columns.
Shore & Bank Sediments	- -	Hand or shovel	Particle size determination by sieves and sedimentation rates in water columns.
Discharge	m ³ day ⁻¹ m ³ year ⁻¹	Gurley Model 625 Velocity meter, metric steel tape	
Conductivity	µmhos cm ⁻¹ at 25°C	Beckman RB3 Solu Bridge	Radiometer CDM2e Conductance meter

Table I continued

Parameter	Units	Field Sampling or Determination	Laboratory Measurements
Salinity	‰ (parts per thousand)	Beckman RS5-3 Electrodeless Induction Salinometer	
Oxygen	mg l ⁻¹ Moles m ⁻³	van Dorn water sampler	Winkler titration
pH	Moles m ⁻³		Radiometer PHM4 or PHM53
HCO ₃ , CO ₂ , CO ₃	Moles m ⁻³		acid titration to inflection point. spectrophotometry
Dissolved Nutrients (nitrogen, phosphorus, silica)	mMoles m ⁻³	filtration, acidification	
Suspended Nutrients	mMoles m ⁻³	retained on filter	C-N analyzer, spectrophotometry
Trace Elements	mMoles m ⁻³	filtration, acidification	Massman graphite cell flameless atomic absorption
Major cations (Ca, Mg, Na, K) + (Mn & Fe)	Moles m ⁻³	filtration	flame atomic absorption
Anions (Cl, SO ₄)	Moles m ⁻³		Ion-exchange resin conductimetry.
Mineralogy	% dry weight		X-ray diffraction
Sediment Organic matter	Moles/g dry weight		C-N Analyzer, Loss on ignition at 900°C.

Table II Summary of Zoobenthos Sampling Methods for Mackenzie-Porcupine Watershed Study 1971.
(For details and references see Appendix VII)

Sampling Device	Area Sampled (sq. cm.)	Mesh Size μ m	Ecological Component Sampled	Remarks
Pole-mounted Ekman grab	524.4	----	Zoobenthos	Streams with soft bottoms
Messenger-operated tall weighted Ekman grab.	225.0	---	Zoobenthos	Streams, lakes and channels with soft bottoms.
Ponar grab	524.4	---	Zoobenthos	Streams and channels with coarse substrates
Petersen grab	614.5	---	Zoobenthos	Channels with coarse or compacted substrates
Kolkwitz dredge	---	300	Epibenthos	Qualitative
Surber sampler	929	405 and 1000	Zoobenthos	Substrate sampled to depth of 5-10 cm.
Artificial substrate sampler	---	---	Zoobenthos	Rock-filled wire basket 18 x 28 cm., cylindrical. Streams and rivers
Drift net	1350	405	Drift	Anchored. Streams and small rivers.
Kick net	---	405	Zoobenthos	Qualitative, Streams and small rivers
Dip net	---	405	Zoobenthos	Qualitative, Streams and small rivers
Sweep net	---	---	Adult insects	Vegetation in vicinity of zoobenthos sampling sites. Qualitative.

Table III Summary of Zoobenthos Sampling Methods for Mackenzie-Porcupine Watershed Study, 1972
(For details and references see Appendix VII)

Sampling Device	Area Sampled (sq. cm.)	Mesh Size µm	Ecological Component Sampled	Remarks
Burton-Flannagan Ekman grab.	225.0	---	Zoobenthos	Channels and lakes
Tube corer	20.4	---	Zoobenthos	Streams and rivers
Sled dredge	---	200 and 400	Epibenthos	Streams and rivers Qualitative
Surber sampler	929	200	Zoobenthos	Streams and rivers
Artificial substrate sampler	---	---	Zoobenthos	Rock-filled wire basket 18 x 28 cm. cylindrical Streams and rivers
Drift net	100	200	Drift	Streams and rivers. Anchored.
Pitfall traps	---	---	Adult insects	Land adjacent to zoobenthos sampling sites. Qualitative. Glycol-filled pans.
Mundie Emergence sampler	---	---	Adult insects	Streams
Cone Emergence trap	1000	---	Adult insects	Qualitative
Sticky Emergence trap	1000	---	Adult insects	Qualitative

6. RESULTS

6.1. Physical and Chemical Data

A summary of dimensions of the watersheds, depths and discharge is given in Appendix IX (Table I).

6.1.1. Temperature

Thermal data for our stations are plotted against time in Appendix IX (Figs. 2 and 3 and Table II). In small rivers of the Fort Simpson and Old Crow regions, the rates of change of temperature in May-June and September-October were great (occasionally exceeding $1^{\circ}\text{C}/\text{day}$). In these small rivers, thermal maxima of $18\text{--}22^{\circ}\text{C}$ occurred in June, July and August in the Simpson region and maxima of $14\text{--}17^{\circ}\text{C}$ occurred in the Old Crow region in June and July.

The larger rivers (Mackenzie, Liard, Peel, Arctic Red, channels in the Delta) were somewhat more sluggish in their response to spring warming and fall cooling, but managed to exceed 16° in July and August. Many thermal discontinuities occurred in cross-sections of the Mackenzie, its tributaries, and the Porcupine River. Great Bear River water in August flowed for over 200 km at 8°C along side the Mackenzie at 16°C . In May and June, the Liard River was usually $4\text{--}5^{\circ}\text{C}$ warmer than the Mackenzie. There were indications that some rivers were supercooled under winter ice. Mackenzie Delta lakes warmed to over 16°C rapidly after the flooding of the region, and cooled very quickly ($1^{\circ}\text{C}/\text{day}$) in September. Delta channels usually reached a thermal maximum of 16°C in July and August. Temperatures in Kugmallit Bay reached 12°C in August, and decreased to 2° in September, and are at or below 0°C in winter.

6.1.2. Turbidity and Suspended Sediments

Data are given in Appendix IX (Fig. 8 and Table VI). There was a great range in these parameters: suspended sediments varied in concentration from less than 1 to over $2,000\text{ gm}^{-3}$, and Secchi visibility varied from 2 cm to over 400 cm. In general, small rivers and rivers with lakes in their headwaters were relatively clear and rarely carried over 25 gm^{-3} suspended sediment. Two notable exceptions were the Hanna and Old Crow River. The Hanna River watershed was recently burned, and has high ice content terrain (Zoltai, personal comm. 1971). The Old Crow River drains the Old Crow Basin which is largely an area of unconsolidated lacustrine deposits (Hughes, 1972). Larger rivers were usually turbid and carried over 100 gm^{-3} suspended sediments throughout the open-water season. In some small rivers, transparency to light was reduced by dissolved organic matter from muskeg or spruce forest drainage. In winter, even the most turbid rivers carried negligible sediment loads (the Liard River at Fort Simpson carried between 500 and $2,000\text{ gm}^{-3}$ in summer, while in March it carried $<10\text{ gm}^{-3}$; Secchi visibility changed from 2 cm in summer to 200 cm under ice). Suspended sediments were usually maximum immediately before and during the spring floods, but occasionally suspended sediment peaks occurred in midsummer when no discharge peaks occurred.

6.1.3. Major Ions in the Dissolved Phase

Data on specific conductance and concentrations of major ions are given in

Appendix IX (Tables II, III, IV and Figs. 3,4 and 5.) The major cations Ca, Mg, Na, and K usually vary inversely with discharge. Maximum concentrations of cations and anions usually occur under winter ice, and minimum concentrations during or immediately after spring floods. Stations in Kugmallit Bay and seaward from the Delta are of course influenced by admixture with seawater from the Beaufort Sea. The concentrations and proportions of ions in Mackenzie Delta lakes appear to be largely controlled by periodic flushing by Mackenzie River floods, the freezing-out of electrolytes from 50% of lake volume in winter ice, by summer evaporation, and precipitation of CaCO_3 on aquatic macrophytes (especially *Chara globularis*). However, frequent exceptions to these generalizations occur, and in some areas are likely related to unidentified subsurface springs of seasonally variable discharges. The influence of the subsurface saline water was greatest during period of low flow, late summer, fall and winter. Na and Cl are often indicators of subsurface waters, and were noticeably high in proportion to other ions in Mackenzie tributaries from the East, for example, Rabbitskin, Harris, Willowlake, Saline and Hare Indian Rivers and in headwaters of some Northern Yukon streams. In most cases, however, variations in conductance (see Appendix IX, Fig. 3, and Table II) were largely controlled by concentrations of Ca and HCO_3 . Extremely dilute water (Caribou Bar Creek headwaters, Conductance = 18 $\mu\text{mhos/cm}$), moderately saline (Saline River, Conductance 2500 $\mu\text{mhos/cm}$) and seawater (Beaufort Sea, salinity = 30⁰/oo) were encountered in the study area.

6.1.4. Nutrients

Concentrations of the dissolved and particulate phases of the nutrient elements P, N, Si, and C for our stations are given in Appendix IX (Tables IV, VII and VIII and Figs. 6 and 7). Dissolved nutrient concentrations varied by over an order of magnitude, being generally in high concentration under ice and decreasing through the open-water season. Concentrations of dissolved nutrients did not appear to be directly related to discharge in most cases. Dissolved phosphorus, usually the nutrient in lowest concentration, appeared to be in higher concentrations in the Porcupine River watershed than the Mackenzie watershed. These nutrients were not reduced to low concentrations by phytoplankton in the productive Mackenzie Delta lakes, as might be expected.

Concentrations of particulate nutrients were directly related to concentrations of suspended sediments in most watersheds. Notable exceptions occurred (see Rabbitskin River and Caribou Bar Creek, Appendix IX, Fig. 7 and 8), and these higher concentrations of particulate nutrients at low discharge periods possibly resulted from the drift of attached algae. In the Delta Lakes, particulate nutrients were closely related to suspended sediment brought to the lake by spring floods, but high particulate, C, N and P under winter ice may have been due to disintegration of aquatic macrophytes. The molar ratio C:N varied greatly from 7 to 90, indicating different sources of carbon in suspension. In general, clear or humic-colored (see Appendix IX, Table VII) waters had lower C:N ratios, indicating that more of the particulate carbon was recently living. Turbid, larger rivers often had higher C:N ratios, indicating a large proportion of decomposed soil and forest debris of greater age, and calcite and dolomite carbon. In clear or humic rivers, N and P occurred in roughly equal proportions in the particulate and dissolved phases. In turbid rivers, particulate N and P was often much greater than in the dissolved phase.

6.1.5. Oxygen and pH.

Data for O_2 and H^+ concentrations are given in Appendix IX, Table II Fig. 3. Concentrations of O_2 were generally low (0-50% saturation) at most stations under March ice. In small rivers, O_2 concentrations increased steadily throughout the open-water season, but rarely reached saturation values. O_2 concentrations during spring flood were often considerably below saturation, and may have resulted from large amounts of particulate organic matter being metabolized. In the few cases where measured, there appeared to be little diurnal variation in O_2 concentration. Large rivers, and to some extent Mackenzie Delta Channels followed this pattern, although generally having higher O_2 concentrations under ice. The Delta lakes that we have sampled were nearly anaerobic under late winter ice, but rapidly became supersaturated with O_2 in August and September. This was likely due to the production of O_2 by the luxuriant growth of aquatic macrophytes.

In the Northern Yukon, concentrations of H^+ varied by 3 orders of magnitude (pH 5-8). In the Mackenzie Valley and Delta channels, pH was more uniform (pH 7.5-8.5) due to the more general occurrence of limestone and dolomite in the area. Even darkly stained humic acid waters were in this pH range. In many of the Mackenzie watershed rivers, calcite and/or dolomite was carried in suspension (see Appendix IX and XI), which will buffer pH to around 8. In the Mackenzie Delta lakes, wherever the water column was clear of Mackenzie sediments and plant growth was rapid, pH often exceeded 9. This was probably due to photosynthesis by planktonic and benthic plants.

6.1.6. Rates of Transport of Suspended Sediments.

Rates of transport (ROT) of suspended sediment (SS) data are given in Appendix X, Tables III, and VIII. The product of suspended material and discharge gave an estimate of the rates of supply of food materials, nutrients, and deleterious substances to the aquatic organisms living in the water. The data indicate a large range in transport rates of suspended matter, from 1-10 metric tons day^{-1} flowing through the Great Bear River station, to 100,000-400,000 mt day^{-1} for the Mackenzie at the Norman Wells station. The inorganic composition of this material did not appear to vary greatly with time, but the organic fraction did vary (see Appendix IX, Tables VI, VII and VIII and Fig. 7) with the season and discharge. Throughout the Mackenzie Valley (we have but limited ROT data for the Porcupine watershed, due to the lack of discharge data), the total mass of sediment moved by water in a year was greatest (10^6 mt yr^{-1}) for tributaries flowing from the Mackenzie and Richardson Mountains (Liard, Redstone, Keele, Mountain, Arctic Red, and Peel Rivers) to the Mackenzie River. Tributaries of the Mackenzie flowing from the East (Horn, Rabbitskin, Willowlake, Great Bear, and Hare Indian Rivers) carried around 10^4 mt yr^{-1} . This partition of sediment source was easily seen from the air: tributaries from the Western mountains were turbid, and Eastern tributaries were either clear or humic acid colored. Small rivers contributed an insignificant sediment load to the Mackenzie in relation to the above mentioned large rivers. The Mackenzie and Peel Rivers deliver about 160,000,000 mt of suspended sediments to the Delta in a year.

To normalize the data from large and small rivers, we have divided the mass of sediment transported by the watershed area. This computation gives an estimate of the mean rate of movement of soils and other particulate

material to a river from a unit area of a variety of different land areas. These data are presented in Appendix X, Table VIII, and indicate that Eastern watersheds, and watersheds of small area and low relief, transported much less sediment (0.01 to 1 metric tons per square kilometer per year) than did the larger tributaries from the Western mountains ($50\text{--}100\text{ mt km}^{-2}\text{yr}^{-1}$). Catastrophic natural disturbances in small watersheds (fire, landslides) will cause high ROT per unit area (e.g. Hanna River, the Caribou Bar Creek landslide), but we have little data on these unpredictable events.

The inorganic material in this sediment was largely quartz, plagioclase, dolomite, calcite, chlorite, illite (see Appendix IX, Table VI). The organic fraction of the sediment load (see Appendix IX, Tables VII and VIII) was largely from boreal forest, tundra soils and vegetation debris. Particulate carbon (PC), particulate nitrogen (PN), and particulate phosphorous (PP) transported by Eastern or small tributaries of low relief ($830\text{--}8,330\text{ moles PC km}^{-2}\text{yr}^{-1}$, $70\text{--}710\text{ moles PN km}^{-2}\text{yr}^{-1}$, $16\text{--}65\text{ moles PP km}^{-2}\text{yr}^{-1}$) was considerably less than that transported by the larger Western rivers ($41,660\text{--}333,300\text{ moles PC km}^{-2}\text{yr}^{-1}$, $3,570\text{--}21,430\text{ moles PN km}^{-2}\text{yr}^{-1}$, $650\text{--}3900\text{ moles PP km}^{-2}\text{yr}^{-1}$). The chemical composition of total suspended sediments is given in Appendix IX, Tables VII, VIII and IX.

6.1.7. Rates of Transport (ROT) of Dissolved Elements.

ROT of the various dissolved elements are given in Appendix X, Tables I and II. ROT for the major ions Ca, Mg, Na, K, HCO_3 , SO_4 and Cl indicate that the Eastern and smaller tributaries of the Mackenzie River transported a smaller total mass of these elements than did the larger Western tributaries, primarily due to the great discharge of the Western rivers. However, ROT per unit area for these elements (see Appendix X, Tables VI and VII) indicate that some Eastern and small watersheds were actually yielding more Na and Cl per unit watershed area than any of the sampled Western river watersheds (see Willowlake, Rabbitskin, Trail Rivers, Appendix X, Tables VI and VII). Elements other than Na and Cl have ROT per unit area that vary in relation to the geology of the watershed. It was noticeable that rather large amounts of Mg and SO_4 are transported from unit area of the Peel and Arctic Red River watersheds.

Data on ROT of dissolved nutrients N, P, and Si are given in Appendix X, Table II and VII. Great variation in the annual mass of dissolved P (as PO_4 and dissolved organic phosphorus) transported by various stations on the Mackenzie and its tributaries was found. Waters leaving Great Slave at Fort Providence carried $1500\text{ metric tons P yr}^{-1}$ in solution, to which the Liard added over 4000 mt P yr^{-1} , Great Bear River added 1500 mt P yr^{-1} , Arctic Red River added 310 mt P yr^{-1} , and the Peel River added 680 mt P yr^{-1} . Smaller rivers (e.g. Willowlake River, 24 mt P yr^{-1} , see also Martin, Jean Marie, Rabbitskin Rivers and Campbell Creek in Appendix X, Table II) add small amounts of P to the Mackenzie River. The mass of dissolved P transported to the Mackenzie Delta by the Mackenzie and Peel Rivers is likely to be on the order of $10,000\text{ mt yr}^{-1}$. The fact that the dissolved P sum of Liard River and Mackenzie River above Fort Simpson was slightly greater than the measured mass of dissolved P being annually transported by the Mackenzie at Norman Wells is an indication of the order of magnitude precision of these types of calculations based on limited data. Several large rivers (Redstone, Keele, and Mountain) have not been

adequately sampled to include them in this calculation, but their contribution has been roughly estimated from nearby watersheds of similar characteristics.

Dissolved N (as $\text{NO}_3 + \text{NO}_2 + \text{NH}_4 + \text{dissolved organic N}$) varied in transport rates over three orders of magnitude ($100\text{--}10,000 \text{ mt N yr}^{-1}$). Part of this great variation may be attributed to the fact that dissolved N has two sources: weathering of surface minerals and soils, and biological fixation of N from the atmosphere. By means of their great discharge, large rivers transported far more dissolved nitrogen than smaller rivers. The annual mass of dissolved nitrogen transported to the Mackenzie Delta by rivers is likely to be on the order of $80,000 \text{ mt}$. The caution attached to the above paragraph on P also applies to N and Si.

Dissolved Si (largely as H_4SiO_4) varied by four orders of magnitude, largely due to variation in discharge of the sampled rivers. The total mass of dissolved Si transported to the Mackenzie Delta by rivers is likely to be on the order of $300,000 \text{ mt Si yr}^{-1}$.

The rate of transport of trace elements in solution cannot be discussed yet, since we have but little data and have experienced severe difficulties in sampling, preservation, transportation, analytical precision and sensitivity. Observed concentrations of selected trace elements are given in Appendix IX, Table VI, and we feel that rates of transport for Fe, Mn, Cu, and Pb will be possible with another year's data.

Rates of transport of dissolved nutrients per unit watershed area (Appendix X, Table VII) gave a clearer picture of the dynamic nature of various watersheds in yielding their nutrient elements to the aquatic ecosystem. Small rivers, or rivers with low relief and many large lakes in their watersheds, had lower rates of transport of dissolved nutrient elements ($32\text{--}320 \text{ moles TDP km}^{-2} \text{ yr}^{-1}$, $715\text{--}1430 \text{ moles TDN km}^{-2} \text{ yr}^{-1}$, $1070\text{--}3570 \text{ moles Si km}^{-2} \text{ yr}^{-1}$) than did larger rivers with mountainous watersheds ($320\text{--}650 \text{ moles P km}^{-2} \text{ yr}^{-1}$, $2140\text{--}5000 \text{ moles N km}^{-2} \text{ yr}^{-1}$, $7,140\text{--}17,860 \text{ moles Si km}^{-2} \text{ yr}^{-1}$).

6.1.8. River and Lake Sediments, Shore and Bank Sediments.

Data on sediment particle size, chemical and mineralogical composition is given in Appendix XI, Tables I-VIII. In general, the river bottom sediments (Appendix XI, Tables I-III) in the Mackenzie-Porcupine River Valleys were composed of sands, gravel and boulders of glacial and fluvial origin. In most rivers, water velocities of $0.5\text{--}2.5 \text{ m sec}^{-1}$ (See Appendix IX, Table I) maintained a clean, scoured bottom, with silts and clays accumulating only in back-eddies and abandoned or low velocity channels. In some cases, the river bottom appeared to be paved with stone and boulders, but finer sediments were found underneath this pavement. In the small, clear rivers of the Old Crow and Simpson regions in summer, the river bottom sediments were often covered with attached algae. In headwaters, especially in mountainous areas, stream beds are composed of relatively unweathered colluvium from adjacent slopes.

In the channels of the Mackenzie Delta, sands and silts are deposited as water saturated levees, but the center of the channel bottom is largely cleanly scoured sand and gravel. Mackenzie Delta lake sediments vary in

composition according to the frequency of siltation due to floods of the river. Frequently flooded lakes (near or connected to the major channels) have largely inorganic silt and clay sediments, while infrequently flooded lakes have a higher percentage of organic matter in their sediments (see Lake 4 and Lake 1, Appendix XI, Table I and II).

In the vicinity of some of our stations (Peel, Arctic Red, Trout, South Nahanni, Porcupine) the river channel is cut into the local bedrock, and shore sediments consist of clean bedrock, boulders and colluvium from the rock wall and overlying alluvium. More common, however, was the occurrence of gravel to silt sized alluvial, lacustrine, and glacio-fluviatile sediments being under-cut by the river channel. Generally, the shore covered by high water levels and exposed during late summer, fall and winter was composed of cobbles and boulders in gravel and sand (e.g. Redstone, Liard at Fort Liard, Mackenzie, Trout). In some rivers (Mountain, Martin, Harris, Liard at Simpson, Trail, Great Bear, Hare Indian, Horn, Rabbitskin, Jean Marie) high waters eroded fine bank sediments away, and bank landslides into the river were common. During and after spring high water in the Mackenzie, Liard, Redstone, Mountain, Porcupine and Old Crow Rivers, silt from these rivers was deposited in the mouths of the smaller tributaries (Martin, Harris, Rabbitskin, Jean Marie, Trail, Willowlake, Caribou Bar, Blackwater and Hare Indian). These latter rivers usually carried small amounts of suspended sediments and had clean substrates upstream. In all cases, the river shore and bank sediments varied greatly along the river channel length.

Our data (Appendix XI, Tables IV-VIII) apply only to our sampling locations, but give an indication of the possible effect of addition of bank sediments to a stream bed (as would occur during pipeline or road construction in the watershed). In general, bank sediments of the Great Bear, Bell, Lord, Hare Indian, Willowlake, Martin, Harris, Jean Marie, Caribou Bar, Rabbitskin Rivers were of smaller particle size and had higher organic carbon (or organic material expressed as Loss on Ignition) (see Appendix XI, Table VI and VII) than did the existing river bottom sediments (see Appendix XI, Table I and II). With the possible exception of the Great Bear River, these rivers have lower discharge and velocities (see Appendix IX Table I) during Summer, Fall and Winter, and are less likely to transport large amounts of silt out of the river channel during these low water periods. Mackenzie Delta Channels usually have silt and sand shore sediment, and bank deposits are being continually eroded, redeposited, and supplemented by each year's Mackenzie-Peel River sediment load. Delta lakes usually have silty shore sediments covered with aquatic vegetation.

6.2. Zoobenthos data.

6.2.1. General ecology.

The mean numbers of invertebrates per artificial substrate of six rivers flowing into the Mackenzie from the east and six from the west were compared. Rivers were arranged latitudinally to eliminate north-south effects (see Table I). An analysis of variance between the two groups shows that a difference ($t = 1.768$; $P \approx 0.10$) exists between them; the mean number in the eastern group being higher. At the taxon level, using per cent occurrence, only the Tipulidae and Simuliidae showed a noticeable difference in occurrence between eastern and western rivers.

Table I. Mean number of invertebrates per substrate in rivers of similar latitude in eastern and western drainages into the Mackenzie River.

East Drainage			West Drainage		
River	Location	Mean Number	River	Location	Mean Number
Rabbitskin	61°47'N	817.3	Liard @ Manners Cr.	61°46'N	40
Harris	61°52'N	642.0	Liard @ Ft. Simpson	61°50'N	146.8
Trail	62°06'N	1400.0	Martin	61°55'N	461.5
Francis Cr.	65°12'N	150.3	Loon Cr.	65°14'N	244.7
Tsital Trein Cr.	67°29'N	152.7	Babaluk Br.	67°28'N	15.7
Pt. Separation II	67°39'N	120.0	No Name 9	67°34'N	39.0

The Tipulidae formed less than 5% of the fauna but were present in most of the northern rivers draining the western side of the Mackenzie north of Norman Wells but were generally absent from the rivers on the eastern side. Low numbers of Simuliidae were found in the northernmost rivers of the western side (e.g., Babaluk Brook - less than 1%) but increased in a southerly direction to a high in the Jean Marie (34%). The eastern rivers showed low percentages at northern and southern extremes of the study area with increases in the Norman Wells area (e.g., Goose Creek - 36%; Billy Creek - 43%).

Samples were taken from the lower Mackenzie system south of the delta during August and September 1971. Stations were located on the Peel, Arctic Red, Ontaratue, Hume and Rampart Rivers and some of their tributaries (Appendix I, Fig. 5). Results are shown in Appendix III.

The Peel River is a large fast flowing river, draining the Richardson and Hart Mountains to the North and the Mackenzie Mountains to the South. It runs clear and in a canyon until its confluence with the Wind River. It then becomes heavily loaded with suspended sediment for the rest of its length. The northern tributaries draining the Richardson Mountains all run in deep (usually sixty meters) and narrow canyons. At the time of sampling all of the tributaries were near high water levels and silty, with the exception of the head-water regions. The floor of each canyon showed evidence of limited braiding. The substrates were all coarse, some made up of angular, shale-like rocks, and others of rounded pebbles, three to four inches in diameter. The East bank of the Caribou River bore evidence of recent forest fires, and the River itself appeared muddier than the rest.

The rivers draining the Mackenzie Mountains were, without exception, widely braided. Their beds, often more than a mile wide, were made up of scores of coarse rubble channels. In late summer-fall 1971, the only river running clear was the Bonnet Plume.

Most of the southern tributaries of the Peel and the northern tributaries of the Arctic Red River drained the boggy, lake-dotted plain between the two rivers. The tributaries were mainly small and the water was humic-colored. Most did not carry large sediment loads.

The southeastern tributaries of the Arctic Red River drain a plateau; their beds, however, were in deeply incised canyons. The substrates were, without exception made up of coarse rubble, and they were all running silty at the time of sampling.

The Hume, Ontaratie, and Rampart Rivers were all deep, slow moving, meandering channels which were silty when sampled.

The fauna of the above area was impoverished even when compared to the Porcupine drainages. The densities varied from 0 to 721 organisms per square meter. The standing crop was greatest at the headwaters of the Richardson Mountain tributaries and the mouths of the Bonnet Plume and Wind Rivers. The lowest standing crops were encountered in the large, turbid rivers such as the Arctic Red and the Peel.

In the Delta of the Mackenzie River, generally speaking, the central region of large channels is impoverished in terms of benthic organisms. There are, however, some notable exceptions to this generalization, although it appears that where the current speed is reduced, e.g., deposition zones, the density of zoobenthos is highest (see Table II).

Table II. Mean annual density of delta channel zoobenthos ($\#/m^2$).

Location*	Density ($\#/m^2$)		
	1 (left bank)	2 (mid-channel)	3 (right bank)
East Channel (7)	226	220	544
Main Channel (4)	38	28	183
West Channel and Peel Channel } Aklavik Channel (6)	164	107	226
Napoiak Channel } Jamieson Channel (4)	186	219	64

* Figure in parenthesis is number of stations sampled.

The majority of benthic organisms in terms of numbers, but not necessarily of biomass, was constituted by dipteran larvae (especially Chironomidae) in the channels. Crustaceans such as Neomysis mercedis, Saduria entomon and Pontoporeia affinis were abundant in the East and Main Channels and there were sporadic local abundances of Trichopteran and Ephemeropteran larvae in East, Peel, Aklavik, and Jamieson channels.

The East Channel is the most productive of all channels sampled in terms of density of zoobenthos. Numbers of organisms per square meter in this channel were approximately twice that of any other channel. The ranking of channels

studied in terms of their zoobenthos production was:

East > Napoiak/Jamieson > West/Peel/Aklavik > Main.

The lakes in the Delta region were the zones of greatest zoobenthos production. Mean annual densities are given in Table III which includes two tundra lakes on the Tuk Peninsula for comparative purposes.

Table III. Mean annual density of Mackenzie Delta lake zoobenthos.

Location*	Density (#/m ²)
Delta floodplain - silty (2)	495
Delta floodplain - clear (7)	6426
Richards Island (2)	4004
Silty lake with channel connection (1)	2156
Long (Shell) Lake (1)	4365
Tuktoyaktuk Peninsula (2)	2091

* Figure in parenthesis is number of lakes sampled.

Delta lake zoobenthos diversity is considerably higher than that of the channels. Chironomid midge larvae still preponderate although their abundance is paralleled by that of gastropod and pelecypod molluscs in many cases. The amphipod Gammarus lacustris was present in all delta lakes sampled, often in high numbers, but was absent from the two tundra lakes (Tuk Peninsula).

The zoobenthos of Mackenzie and Kugmallit Bays was primarily marine. The zoobenthos density of these areas is summarized in Table IV. There was an increase in abundance and diversity moving from the predominantly fresh to the predominantly marine zones, i.e. from south to north in **this area**. The limits and range of salinity and temperature in the estuarine zones are given in Appendix II.

Table IV. Mean annual density of zoobenthos in the brackish zone of the Mackenzie Delta (#/m²).

Location*	Density (#/m ²)
Kugmallit Bay (4)	689
Beaufort Sea - east of Pullen Island (6)	2338
Mackenzie Bay - Garry Island to Pullen Island (4)	200
Mackenzie Bay - Shingle Pt. to Garry Is. +Shallow Bay (4)	46

* Figure in parenthesis is a number of stations sampled.

The shallow inshore areas were characterized by mobile forms such as amphipods. Pontoporeia affinis was especially abundant in the vicinity of Hooper Island. The cumacean Disastylis sulcata was also very numerous in these areas although polychaetes appeared to be the most abundant group at each location sampled. Marine bivalves occurred at the more northern stations, in association with a single species of gastropod (Cylichna sp.) and polychaetes.

During winter the terrain was frozen, erosion was minimal, discharge of flowing systems was minimal, and rivers which were turbid during the open water season ran clear under the ice. A limited winter sampling programme in the Mackenzie delta was begun in 1971 and expanded during 1972. It was therefore possible to make a comprehensive study of the zoobenthos throughout the year, including the abundance of organisms during winter.

Four sampling locations were chosen as being representative of aquatic habitats within the delta. These were a silty lake (L.1), a clear lake (L.4) and two stations on the East Channel, above (EC1) and below (EC3) Inuvik. Zoobenthos abundance for these four locations is given in Table V.

Table V. Zoobenthos standing crop of representative Mackenzie delta habitats. August 1971-December 1972.
(* denotes months with ice-cover)

Date	Number of organisms per square meter			
	Lake 1 (silty)	Lake 4 (clear)	East Channel (EC1)	East Channel (EC3)
Aug. 1971	-	-	606	329
Sept. 1971	336	4088	-	-
* Dec. 1971	322	-	2380	1204
* Mar. 1972	112	2870	2478	210
* May 1972	-	1106	-	-
June 1972	406	-	4256	476
July 1972	-	2006	322	-
Aug. 1972	182	-	-	70
Sept. 1972	196	3969	-	1946
* Nov. 1972	518	-	2590	-
* Dec. 1972	-	-	-	3052

In all four habitats, chironomid larvae were numerically dominant over the period of study. In the lakes, gastropod and bivalve molluscs were also abundant with lower densities of other taxa, some of which may appear in larger numbers temporarily at certain times of the year. The same is generally true for the two East Channel stations, although here the taxon diversity is much lower than in lakes, and oligochaetes are more in evidence. Station EC1 was characterized by large numbers of the amphipod Pontoporeia affinis as well as chironomid larvae. EC3 had high densities of net-spinning caddis larvae as well as chironomid larvae.

It can be seen from Table V that zoobenthos densities during winter represented a sizable fraction (from approximately one third to one half) of the peak summer value. In the case of L.1 and EC3 the winter densities exceeded the highest recorded summer value.

Chironomid larvae collections during November and December contain large numbers of early instars. Most of the caddis larvae taken at this time were also at an early stage. The Pontoporeia population during winter is a mixture of juveniles and adults and a few gravid specimens. During November and December 1972 all specimens taken in grab samples were females.

A plankton net set in the East Channel (EC10) during November and December 1972 collected large numbers of calanoid and cyclopoid copepods under the ice. Numbers of these copepods declined gradually over the sampling period from 5900 per day (22 November) to 900 per day (12 December).

Very few drifting zoobenthic organisms were taken by this net over the same period although they did include some juvenile and adult specimens of Pontoporeia. Several specimens of this amphipod were also collected from artificial substrate samplers set in the same location at the same time. These and the net specimens were mainly males.

The study of the Northern Yukon Porcupine River system in 1971 made it possible to characterize streams according to three major categories. The first of these categories was the Alpine Creek (A). Such waters are partly above the tree line, both pools and riffles having a rocky substrate, and at least half of such a stream would be riffle areas. These waters are usually free of turbidity and contain large numbers of invertebrates. Benthic assemblages were dominated by Chironomidae, Plecoptera and Ephemeroptera although smaller numbers of Simuliidae and Hydracarina also occurred.

The secondary category was designated as Foothill Streams (B). In each habitat there were areas of coarse sand and gravel deposition where bottom sediments had low stability. Sand was deposited in pools of this type of creek. Such creeks were deeper with steeper banks and overhanging vegetation. The current was generally slow and over half the stream bed consists of pools. The lowest numbers of zoobenthos were characteristic of this zone (B) (see Table VI-VIII).

Large meandering Floodplain Rivers comprised the third category (C). These were usually wider, slower and meander more than the previous two types. The water was often silty and sand-deposition was usually common along shores composed of clean pebbles. The pH was usually quite high, (8.0-8.5) compared to headwaters. Zoobenthos abundance usually showed a slight increase in this zone (C). Chironomidae were still dominant, followed by Ephemeroptera. Plecoptera and several other groups were absent. The zoobenthic organisms in these three stream types are shown in Tables VI-VIII.

Table VI. Numbers of benthic organisms per m², using a Surber sampler, at different stations in each zone, August - September 1971. A dash indicates that no animals were found in the sample.

		Bell River													
		Old Crow River													
Type A		Plecoptera	Ephemeroptera	Trichoptera	Chironomidae	Simuliidae	Tipulidae	Ceratopogonidae	Gastropoda	Pelecypoda	Oligochaeta	Hydracarina	Amphipoda		
Type A	86	527	108	11	301	-	-	-	-	-	-	-	-	334	
	527	108	11	194	22	-	-	-	-	-	-	11	-	1679	
	54	22	43	269	32	-	-	-	11	-	-	75	-	1592	
	108	140	-	344	-	-	-	-	-	-	-	-	-	1323	
	236	258	11	452	-	11	11	-	-	-	-	-	-	1151	
	280	269	-	420	-	75	54	-	-	-	-	97	-	2260	
	247	97	226	1453	11	-	32	-	11	-	-	-	-	-	
	226	-	377	710	-	-	194	-	-	-	-	-	-	-	
Type B	732	118	75	1141	-	11	65	-	-	-	-	-	-	-	
	11	11	86	-	-	-	22	-	-	-	-	-	-	118	
	-	11	-	86	-	-	11	-	-	-	-	11	-	269	
	43	22	-	495	-	11	11	-	-	-	-	-	-	-	
	22	-	-	32	-	-	-	-	-	-	-	-	-	-	
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	-	11	-	11	-	-	-	-	-	-	-	-	-	-	
	22	-	-	11	-	-	-	-	-	-	-	-	-	-	
Type C	-	11	22	140	97	-	22	-	-	-	-	11	-	75	
	-	32	11	140	43	-	11	-	-	-	-	11	-	65	
	11	22	11	161	11	-	11	-	-	-	-	-	-	22	
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	

Table VIII. Numbers of benthic organisms per m², using a Surber sampler, at different stations in each zone, August - September, 1971.

Bluefish River										South Slope Rivers										Driftwood River																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																												
Plecoptera		Ephemeroptera		Trichoptera		Chironomidae		Simuliidae		Tipulidae		Ceratopogonidae		Gastropoda		Pelecypoda		Oligochaeta		Hydracarina		Amphipoda		Plecoptera		Ephemeroptera		Trichoptera		Chironomidae		Simuliidae		Tipulidae		Ceratopogonidae		Gastropoda		Pelecypoda		Oligochaeta		Hydracarina		Amphipoda																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																		
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fluctuations in zoobenthos communities known to be taking place as evidenced by the Caribou Bar Creek mud slide and oil spill studies (Tables X and XVII). The three categories presented do not imply that a whole stream need belong to any one class. As is often the case, portions of streams belong to one class. This is illustrated in Tables VI-VIII. The rivers of the Porcupine River watershed were characterized by the presence of Chironomidae, Hydracarina, Plecoptera, Ephemeroptera, Simuliidae, Trichoptera and Tipulidae ranked in this order. In rivers of type B and C there was a noticeable decrease in Trichoptera and Plecoptera. (Tables VI and VIII). Tables VII and VIII contrast four rivers of similar size; two of which are located entirely above the treeline (Table VII), and two of which are south of the treeline. (Table VIII).

Thirty-one rivers along the Mackenzie mainstem (60°14' N to 67°39' N) were compared for latitudinal trends in fauna. Mean number of invertebrates per artificial substrate is plotted against latitude in Fig. 1. The trend was towards increased mean numbers with decreased latitude. When the per cent occurrence graphs were compared, latitudinal trends were visible in the Ephemeroptera, Trichoptera, Simuliidae and Hydracarina. The Ephemeroptera usually formed less than 5% of the fauna north of Fort Simpson but increased in and south of the Fort Simpson area to three and six times that amount in the Rabbitskin and Harris Rivers respectively. Generally, the Trichoptera formed a lower per cent of the taxa in the more northern rivers. Their high was reached in the Rabbitskin (20%). The Simuliidae showed a definite trend in constituting a higher per cent occurrence in the south, reaching a high at the Jean Marie (34%). The more northern rivers were almost devoid of Simuliidae in these September samplings. The Hydracarina usually formed less than 5% of the fauna in many rivers. They too occur more frequently in the southern reaches of the Mackenzie system. None were found north of the Norman Wells area. In summary then, these elements of the fauna may be exhibiting a seasonal effect or may be reflecting the generalization that diversity decreases in a northerly direction.

In addition to the latitudinal effects reported above, it is possible to make generalizations concerning the zoogeography of the study area in terms of zoobenthos distribution utilizing the data obtained to date. This was accomplished using the data of Appendix V and by considering only the presence or absence of various invertebrate taxa. Due allowance was made for the fact that more taxonomic data are currently available for some areas than others in the treatment of these data. Genera of aquatic insects were primarily considered and as lakes were only sampled in one of the three major study areas, these genera had to appear in at least one flowing water system.

The results showed that there were 166 genera present in the Mackenzie mainstem around Fort Simpson, 59 genera in the Mackenzie Delta, and 130 in the Northern Yukon. Since all identifications are far from complete we can expect many additions in the future. At all three stations the majority of the genera were contributed by the Diptera (53.0% Fort Simpson; 64.4% the Delta; 66.9% Northern Yukon). The rest are shown in Figure 2A.

Due to the large taxon diversity of the Chironomidae, (61 genera at Old Crow, 34 in the Delta and 45 in Fort Simpson) and because they have often been used as indicator organisms (Brundin, 1958) this family was given special attention.

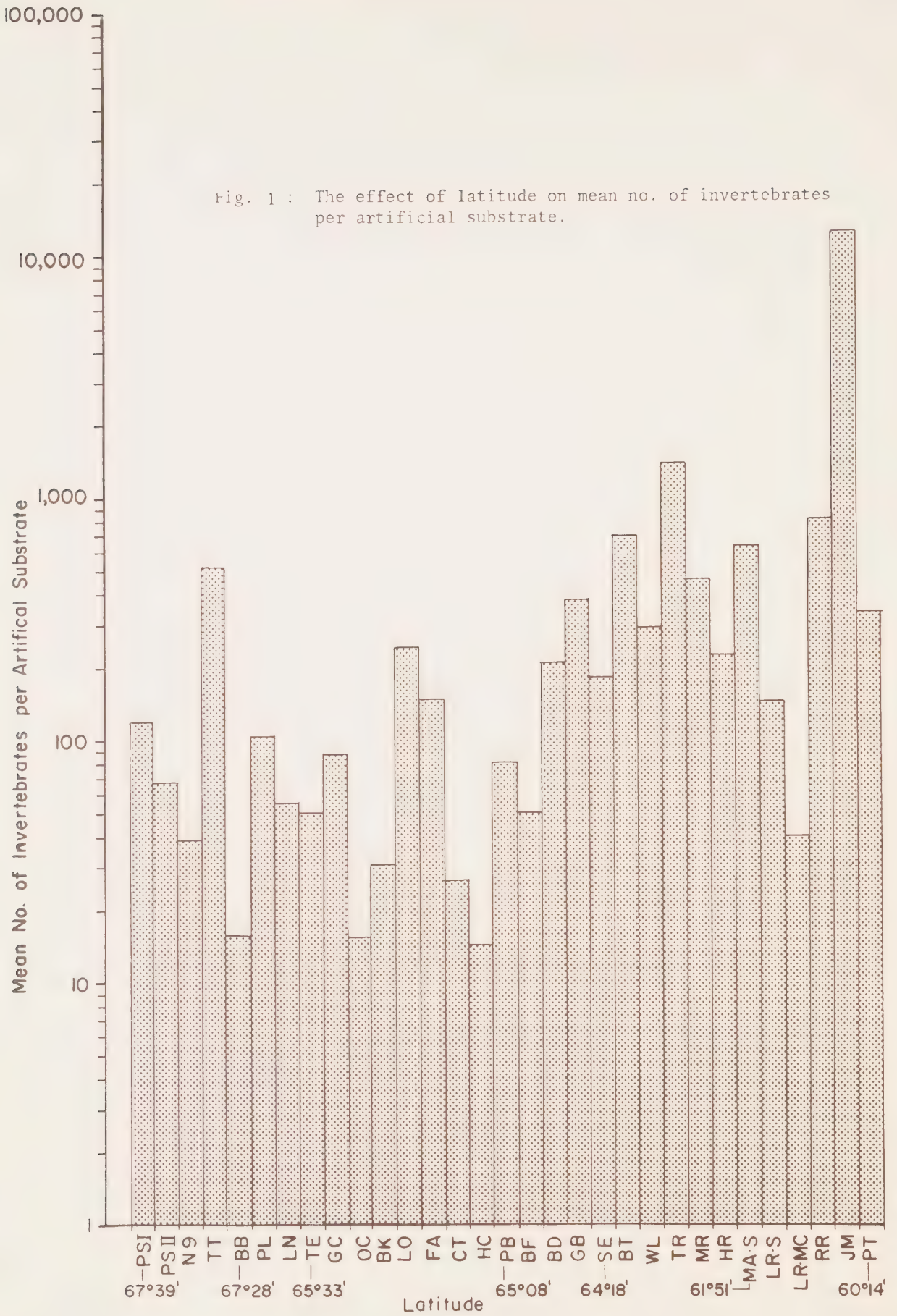
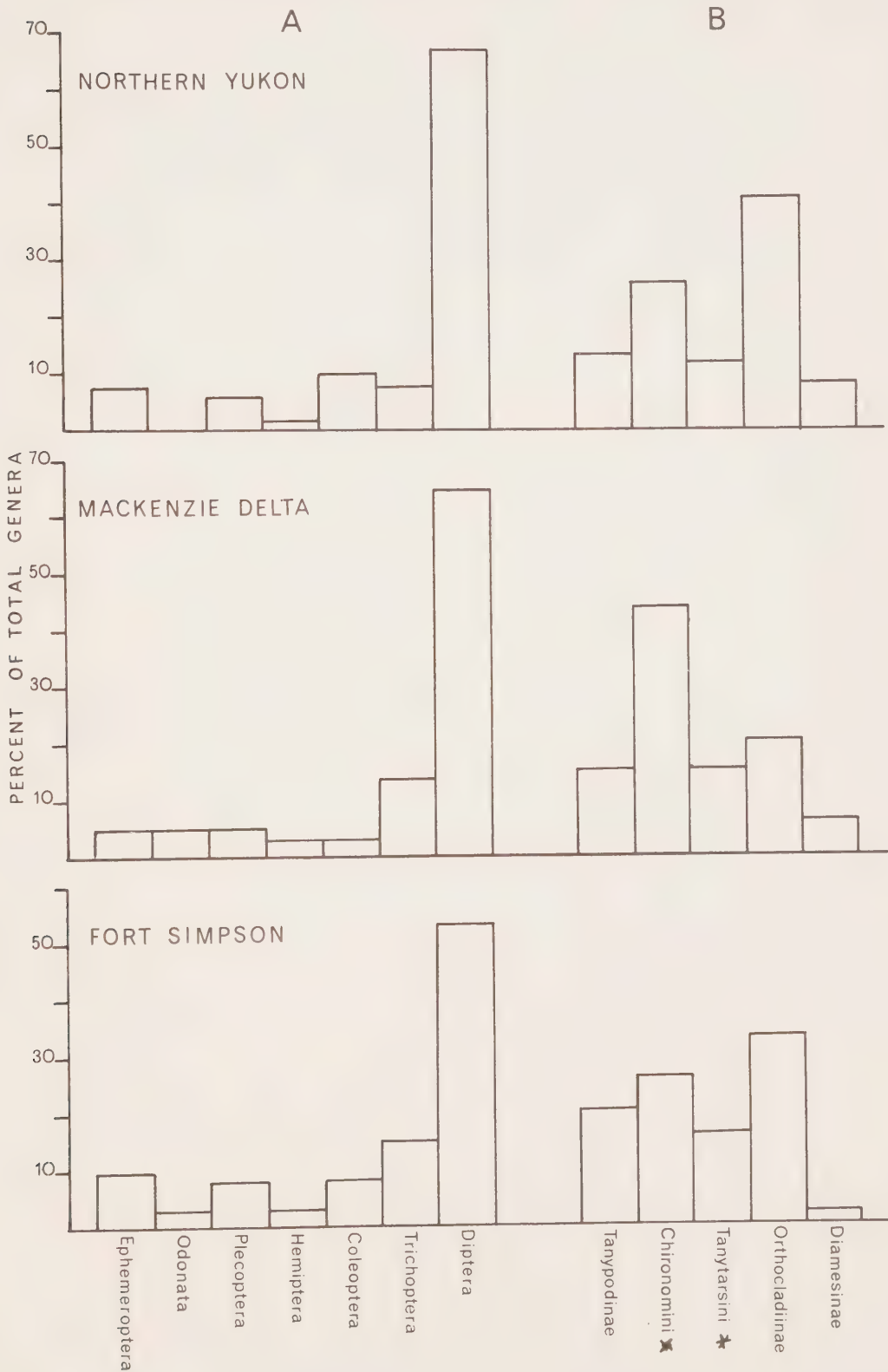


Fig. 2 A) Distribution of the aquatic insect orders represented as percent of total genera collected in the three sampling areas.
B) Composition of the Family Chironomidae in the three areas represented as percent of total genera present.



(* denotes tribes of subfamily Chironominae)

The percent occurrence of the Chironomidae, subdivided into the various sub-families are shown in Figure 2B. It was apparent that in the Upper Yukon the chironomid fauna was dominated by Orthocladiini, in the Delta by Chironomini, and in the Fort Simpson region by a fairly close distribution of Orthocladiini, Chironomini and Tanypodini. Another interesting feature is the variation in occurrence of Diamesinae, a group which is characteristic of oligotrophic conditions.

The Oligochaeta and Mollusca are the only freshwater invertebrates for which we have good species identifications to date. Of the 16 genera of Oligochaetes represented, 22 species are found at Fort Simpson, 18 species in the Delta, and 11 species in the Northern Yukon. Of the 12 genera of molluscs represented, 17 species were found at Fort Simpson, 22 in the Delta and 6 in the Northern Yukon. The distribution of these two phyla are summarized below as percent of total species present throughout the Mackenzie-Porcupine watersheds.

	<u>Mollusca</u>	<u>Oligochaeta</u>
Delta only	33.33	22.58
Yukon only	-	12.90
Fort Simpson only	14.81	45.16
Fort Simpson and Delta	29.63	3.22
Yukon and Delta	3.70	9.68
Fort Simpson and Delta	-	3.22
Fort Simpson, Delta and Yukon	18.52	3.22

6.2.2. Effects of Oil on Zoobenthos

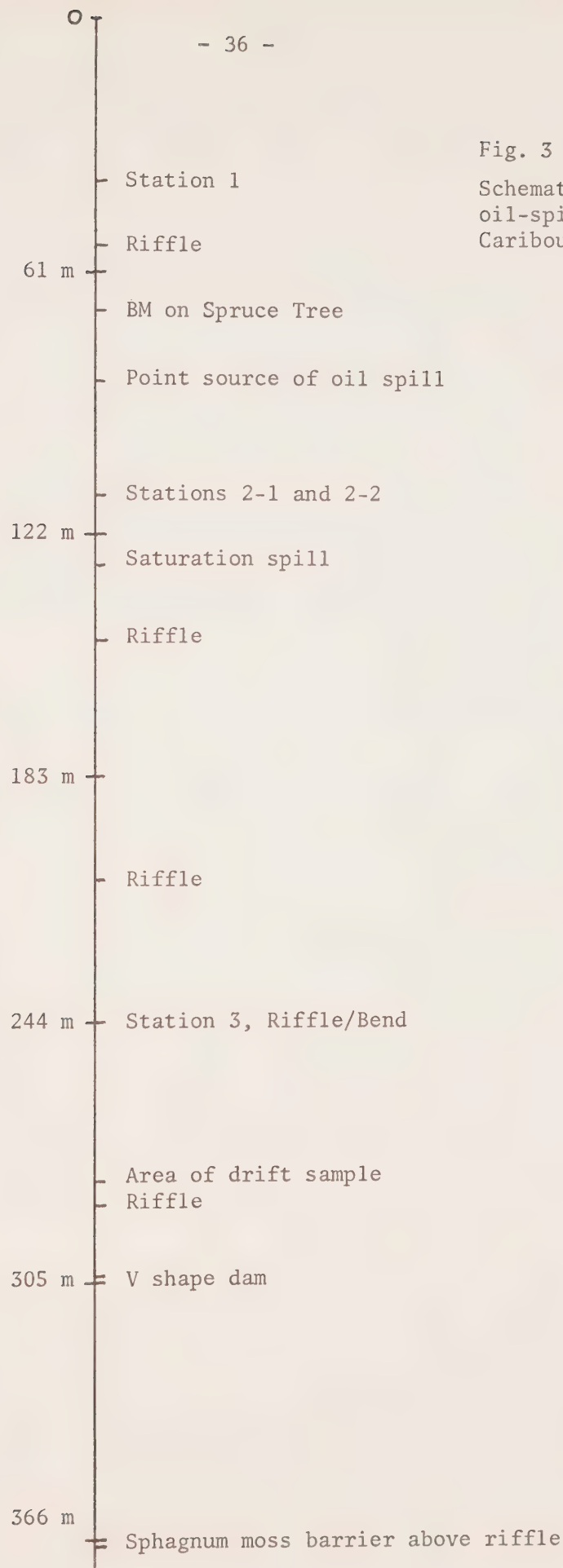
6.2.2.1. Caribou Bar Creek Oil Spill Experiment

The oil was pumped onto the stream 16 August 1972, 1437 hr at the "point source" (Fig. 3). Air temperature during the experiment was between 7-14°C, and water temperature was between 9 and 11°C. There was a light northerly breeze, and it rained for 2 1/2 hours in the evening after the spill. Due to the helicopter's downdraft, the oil spread quickly across the channel, but remained thickest on the eastern shore, where artificial substrate samplers were installed. From the air the oil appeared as a light blanket, dampening the surficial turbulence at the riffle area. Upon reaching each riffle the oil slick was momentarily arrested, only to shoot downstream a few seconds later alongside one of the banks where the water was deepest. Because of this behaviour, several sections of the stream in the lee of the riffles were not exposed to the oil, and different sections of stream were exposed to varying concentrations of oil. The oil slick had a mean velocity of 0.6 m sec⁻¹ over the 210 m of experimental stream, compared to a mean water velocity of 0.7 m sec⁻¹.

The oil slick reached the drift nets which were sampling the lower 10 cm of water at 1444 hr. By this time the oil was well mixed in the water column, appearing as a yellow, frothy mixture of oil, water and debris. Oil was recovered in drift nets and water samples. When the oil reached the dam it was momentarily stopped, but turbulence carried the slick under the barrier, even though the barrier extended about 30 cm under the surface. The first moss barrier, on the other hand, managed to keep the oil from filtering through, primarily because it was set in a shallow riffle and the water had to percolate through it. Unfortunately the water backed up and eventually

Fig. 3

Schematic drawing of the
oil-spill study area -
Caribou Bar Creek.



flowed over the moss barrier. A second moss barrier, a floating one, placed downstream was about as efficient as the floating dam.

Immediately the drift of all taxa increased markedly, the first response being shown by the Chironomidae and Hydracarina (Fig. 4). This was followed by an even greater increase in the Ephemeroptera, Plecoptera, and Trichoptera. Secondary peaks occurred in the various taxa at different intervals after the spill (Fig. 4). Total drift magnitude was 6 times that of the previous week (Fig. 4 and Table IX). During that same period the drift intensity in the control stream dropped 50%, probably due to seasonal effects (Fig. 5 and Table IX). Assuming that we could expect a similar drop in the experimental creek, then the actual increase in drift intensity due to the oil was 12 times the expected (Table IX).

Approximately 24 hours after the spill and two weeks later, Surber samples were collected at each station; results of the station which received the maximum exposure to oil (Station 3) and the upstream control (Station 1), are shown in Table X. Between the 12th and 17th of August, total numbers of benthos were reduced at all stations, including the control No. 1 which was not exposed to oil. However, in the oiled section the numbers sampled were 2/3 of those in the controls (Table X).

Two weeks later (August 31st) the numbers had increased at least 10 fold at all of the stations on Caribou Bar Creek, the oiled stations being no exception (Table X).

Oil was present in the sediment at stations within the oil-spill area and could be released from the substrate by kicking as late as August 31st.

6.2.2.2. Delta Lake Oil-Spill Experiment

Lake 4 in the Mackenzie Delta is shallow (average depth 2.3 m) and is located centrally between Inuvik and Aklavik, to the west of the main channel. Bathymetric data are presented in Appendix IX, Fig. 1. The lake is surrounded by typical dense Delta brush (spruce, willow and alder), and it supports a high standing crop of macrophytes during summer (for macrophyte species see Appendix V). There was no thermal stratification during summer although inverse stratification occurred in winter. During summer, aquatic macrophytes grew profusely in the lake, producing a supersaturation of O₂ and pH values of 9-10. After Mackenzie flood waters left the area in June, Lake 4 was relatively free of inorganic suspended sediments and one could see to the bottom of the lake easily. During winter (1971-72), O₂ was likely consumed by decomposing aquatic macrophytes in the lake, and O₂ concentrations in March were zero.

Microorganism population data are given in Fig. 6. This figure summarizes the counts obtained from filters incubated aerobically at 15°C. The counts represent the heterotrophic bacterial populations which are capable of utilizing Tryptic Soy broth as a nutrient source and do not necessarily reflect the true microbial population sizes in the lakes.

The species composition of the profundal benthos of Lake 4, in terms of taxa identified to date, is given in Appendix XIV, Table II. Chironomid larvae gastropod and pelecypod molluscs exhibited the greatest diversity. The

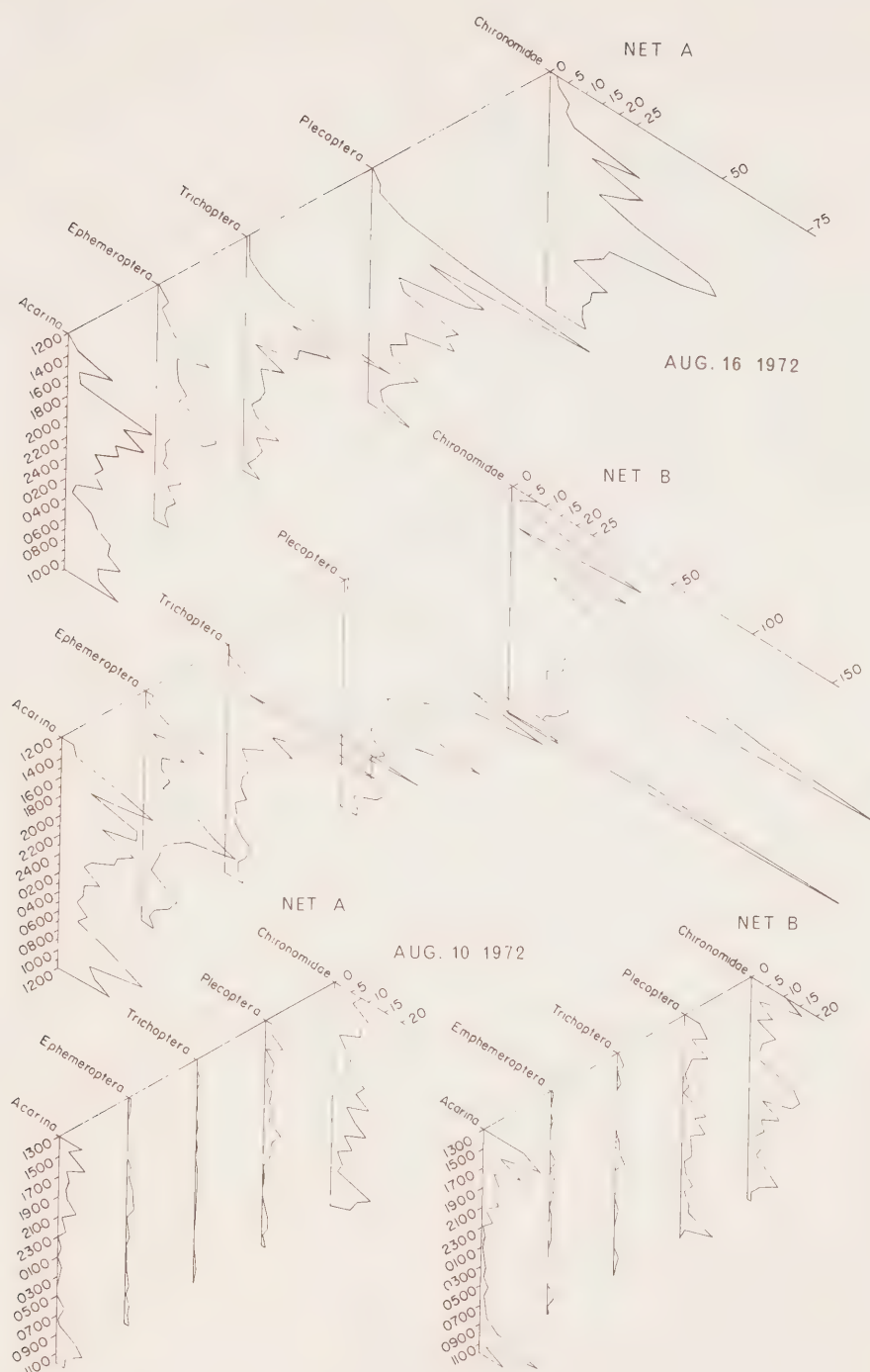


Figure 4

Drift patterns of Experimental creek (Caribou Bar Creek) as shown by two nets (A and B) on two sampling occasions (aug. 10 and Aug. 16, 1972). The oil spill experiment occurred on 16 August, and is the cause of the great increase in drift on that date.

Ordinate: numbers of drifting organisms/net hr.
 Abscissa: time (hrs.) with reference to 24 hr. clock.
 Baseline: taxa.

Table IX. Per cent composition of major taxa and total numbers (#/300 cm² 24 hrs) drifting in the oil treated and untreated tributary of Caribou Bar Creek.

	Acarina	Plecoptera	Ephemeroptera	Trichoptera	Chironomidae	Totals
Before spill 12.08.72	Control Ck. Experimental	30.91 30.32	20.71 19.97	3.03 2.77	5.96 2.91	39.80 41.39
						466 686
During spill 16.08.72	Control Ck. Experimental	18.76 16.30	33.47 27.70	5.75 10.14	7.67 12.29	31.55 32.56
						235 4140

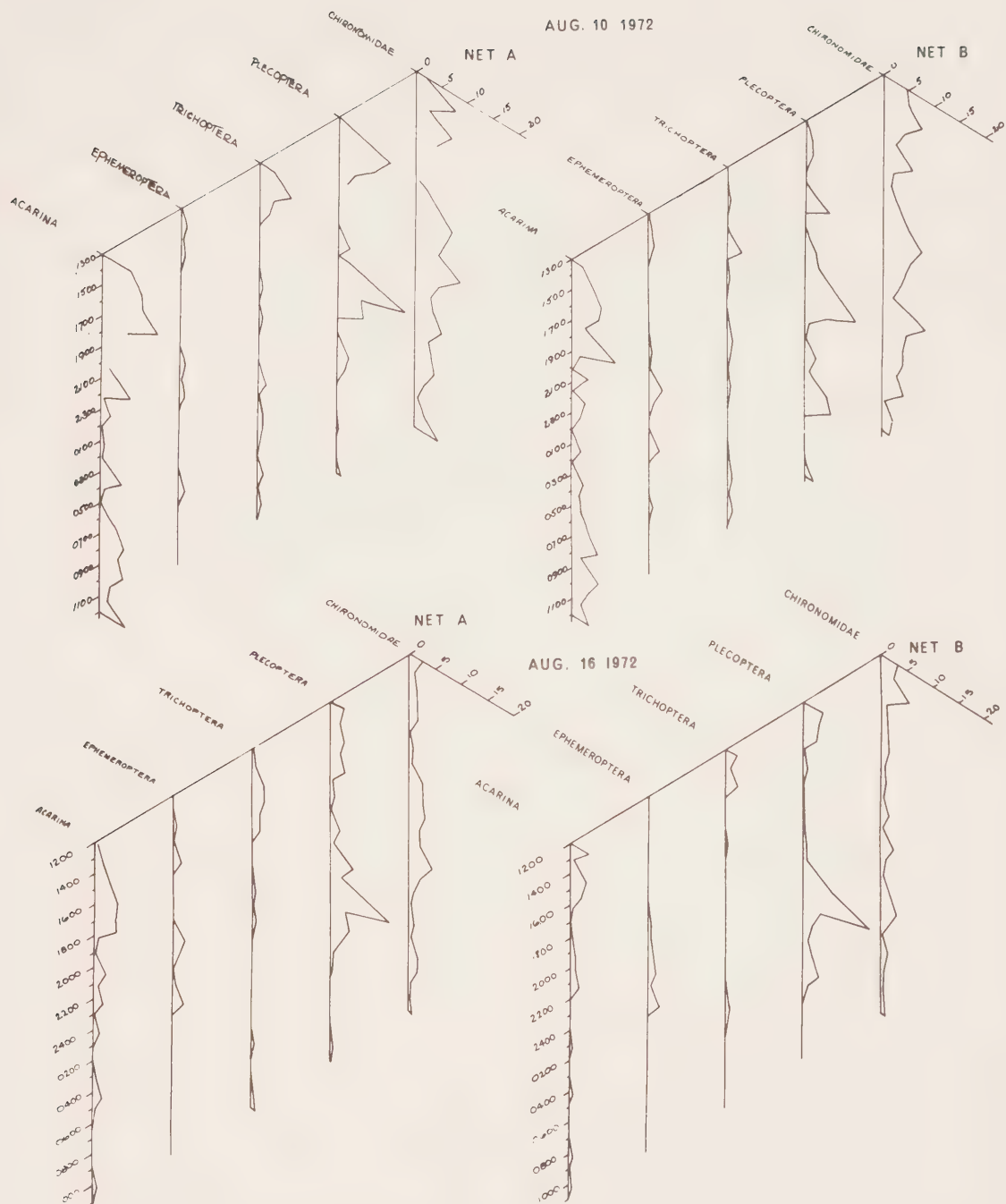


Figure 5

Drift patterns of Control creek (Caribou Bar Creek) as shown by two nets (A and B) on two sampling occasions (August 10th and August 16th, 1972)

Ordinate: numbers of drifting organisms/net hr.
 Abscissa: time (hrs.) with reference to 24 hr. clock.
 Baseline: taxon

Table X. Estimated numbers of zoobenthos per m² present in the sediment before and after the oil spill at two stations. Station 3 received oil and station 1 did not. The oil spill was on August 16, 1972.
A dash (-) indicates that no organisms of that taxon were collected.

12.08.72			17.08.72			31.08.72		
	Sta. 1	Sta. 3		Sta. 1	Sta. 3		Sta. 1	Sta. 3
Oligochaeta	14	14	-	-	-	11	4	
Plecoptera	118	531	25	27	355	79	355	
Ephemeroptera	57	118	4	59	4	18	4	
Trichoptera	18	57	-	16	57	22	57	
Tipulidae	82	25	4	5	4	25	4	
Simuliidae	-	14	-	-	7	-	7	
Chironomidae	1506	1151	316	129	3074	4447	3074	
Ceratopogonidae	-	-	-	-	-	-	-	
Empididae	-	-	18	-	18	22	18	
Rhagionidae	-	14	-	-	-	-	-	
Acarina	100	154	-	5	337	118	337	
Est. total numbers per m ²	1895	2078	367	241	3860	4742	3860	

FIGURE 6

Counts obtained on Tryptic Soy dishes from samples of water and mud of L4 and LC4. All dishes were incubated aerobically at 15°C.

Curve 1: L4 water at 1 M depth ⁽¹⁾

Curve 2: LC4 water at 1 M depth

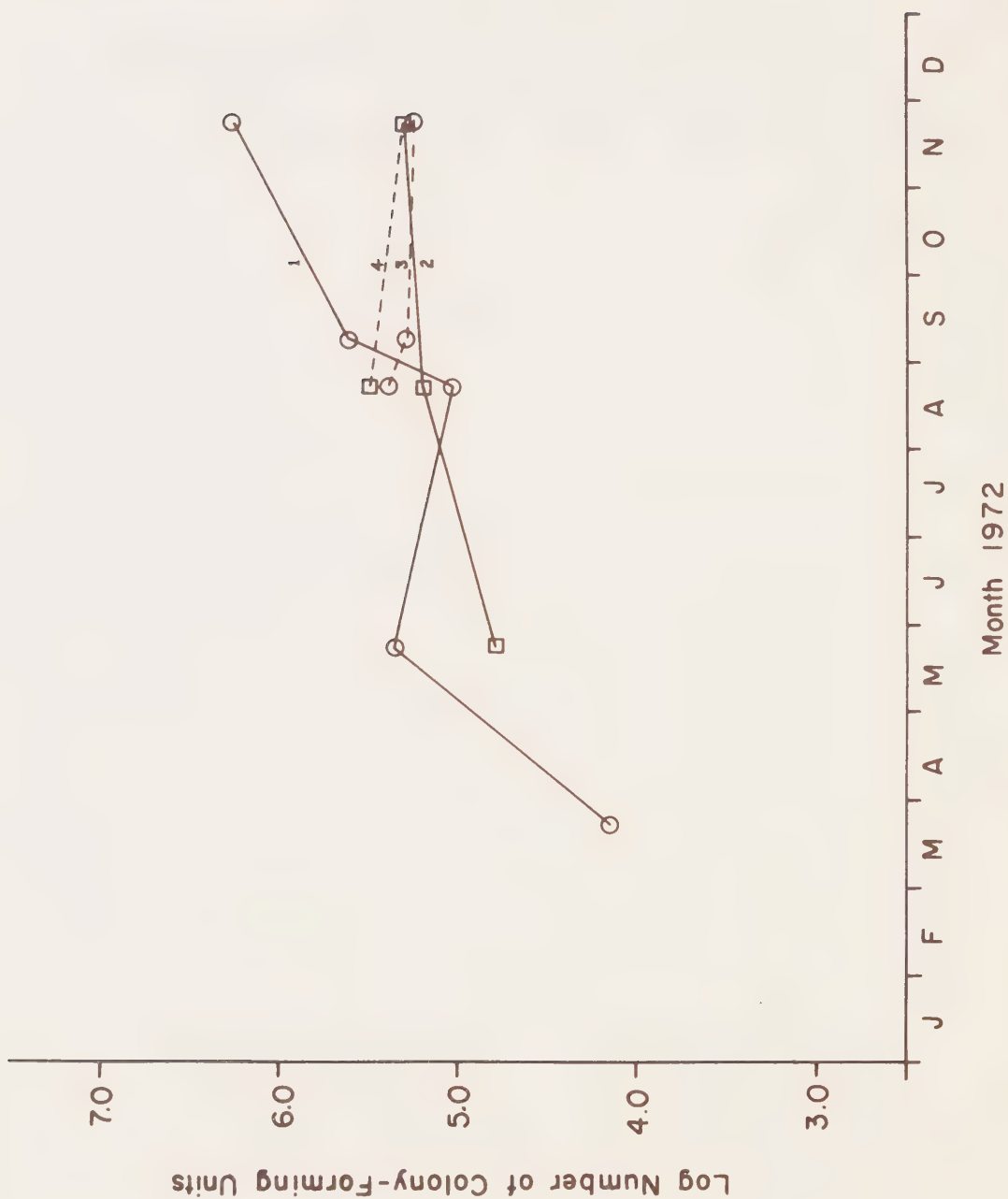
Curve 3: L4 surface mud ⁽²⁾

Curve 4: LC4 surface mud

⁽¹⁾Water counts expressed as log number of colony-forming units/one litre of water

⁽²⁾Surface mud counts expressed as log number of colony-forming units/one ml of mud

Fig. 6



abundance (= standing crop) of profundal benthic invertebrates in the lake over one annual cycle is given in Appendix XIV, Table III. The major taxa are also broken down in terms of percentage occurrence in this table. The density range was 854-4172 animals/m² in July and September, 1972, respectively. The mean annual density was 2,859 animals/m². Chironomid larvae comprised the dominant group of animals in this habitat (62.4%). The percentage occurrence of all taxa are presented in Appendix III.

The numbers and taxa of littoral benthic invertebrates occurring in the oil film and 0.5 m below the experimental plot before and after the spill are presented in Fig. 7, and their diversity in Appendix XIV, Table IV.

Very small numbers of both individuals and taxa occurred in the surface film prior to the spill (Coleoptera, Gerridae and Chironomid larvae). There was a twenty-fold increase in this number of benthic invertebrates one day after the spill (see Table XI). In addition many more taxa were represented in the oil-film than occurred at the water surface prior to the spill.

Table XI. Numbers of invertebrates per m² in the surface-film and littoral of the Lake 4 experimental plot before and after the spill.

Date	Invertebrates/m ²	
	Surface-film	Littoral
4.9.72	19	
5.9.72		1088
oil spill		
6.9.72	358	
12.9.72	213	315
19.9.72	125	688
23.11.72		718

Organisms trapped in the oil-film one day after the spill are shown in Fig. 8. Sticklebacks (Pungittia) are also included in this sample. Shoals of these fishes and larger lake chub (Couesius) were seen to aggregate under the oil slick shortly after its formation and even to take insects as they became trapped in it.

Concomitant with the increase in numbers of organisms in the surface film, there was greater than a third reduction in the numbers of littoral benthic organisms beneath the film. All littoral species suffered a reduction in numbers, and no leeches, oligochaetes or mayfly nymphs were found. These three taxa had re-colonized the area, however, two weeks after the spill. By November (two months after the spill) the numbers of littoral benthos were at the two weeks post-spill level which is two thirds of the pre-spill abundance. At this time (November) it can be seen (Fig. 7) that the relative abundance of various taxa had changed. Amphipods (Gammarus lacustris) and mayfly nymphs (Caenis sp.) were far more numerous whereas pelecypods were present in reduced numbers.

Also at this time the lake exhibited inverse thermal stratification under 40 cm of ice. Oxygen was deficient at the bottom of the lake at its centre (0 mg/l)

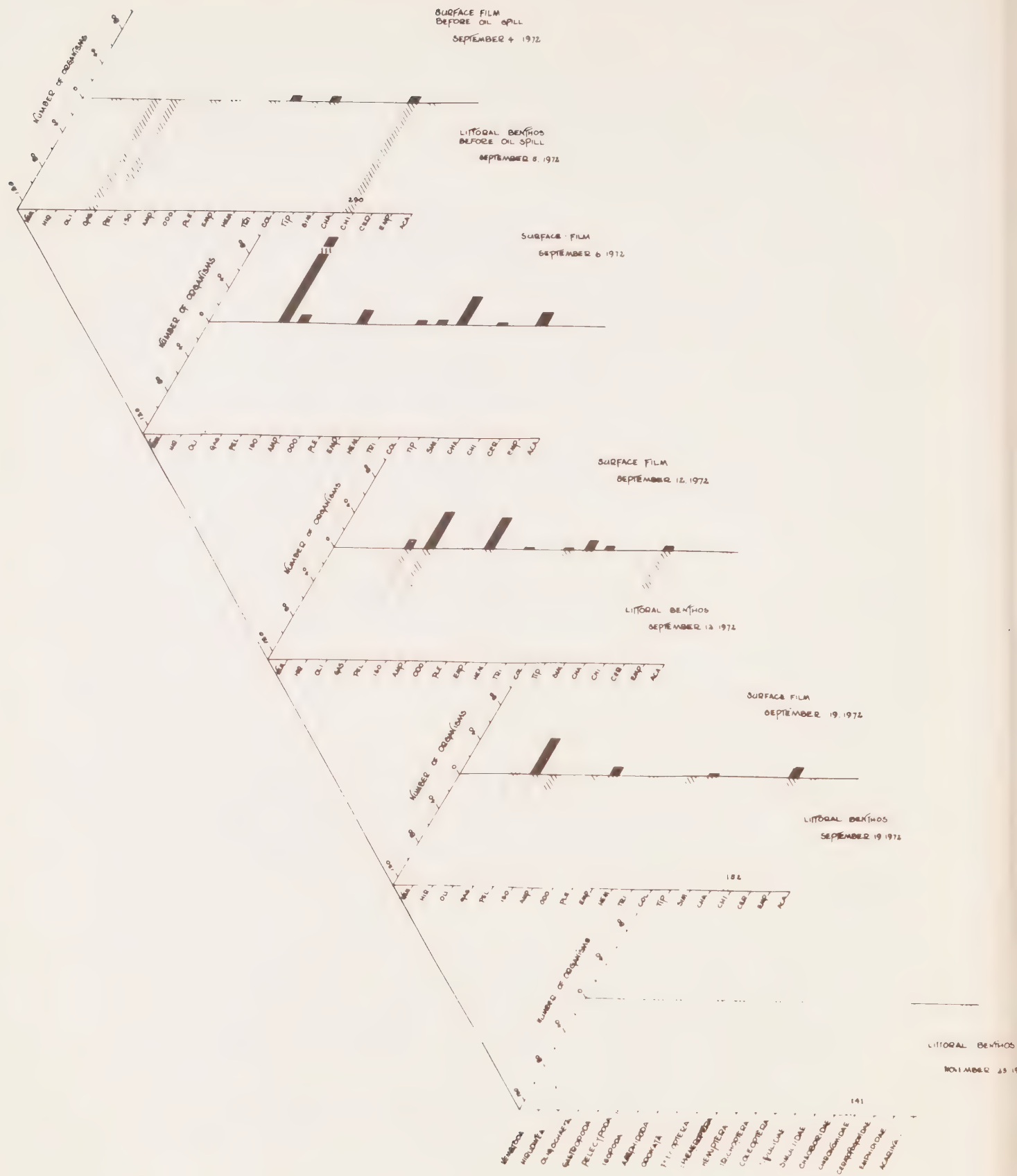


Fig. 7 Numbers of organisms in the surface film and littoral of experimental plot, Lake 4, before and after spill. (spill occurred 5-IX-72)

Fig. 8: Organisms collected from the oil-film on Lake 4 one day after the spill.



but surface waters were at saturation (13.6 mg/l). At the site of the experimental plot, the oxygen level had decreased to 8.0 mg/l and at the extreme lake margin where oil was still in evidence in the sediment below the ice, the oxygen concentration was zero. At this shore station reducing conditions prevailed, and the odor of hydrogen sulphide was very much in evidence.

6.2.2.3. Yellowknife Bay Oil Spill

The sampling areas are shown in Fig. 9. The average number of organisms per square meter was twice as large in the shallow, polluted bay as in the control (Table XII). The composition, however, differed markedly, with Amphipoda, Trichoptera, Tipulidae, and Coleoptera absent in the disturbed bay. Plotting presence and absence of individual taxa (Appendix XII, Fig. 1) makes the differences between the two bays even more apparent..

At the 2.0 m station there was an 81% reduction in numbers of benthic organisms in the polluted area compared to the same depth in the control area, for all taxa except the Oligochaetes. A shift in dominance occurred, from Amphipoda in the undisturbed area to Oligochaeta in the disturbed area (Appendix XII, Fig. 2). The difference in taxa and abundance of benthic organisms in the shallow (0.5 m) bay stations (control and oil-polluted bays) was much greater than the difference among the deeper stations in oil-polluted and control areas. At the 4.75 m stations (Appendix XII, Fig. 2) there was a 50% reduction in total numbers in the disturbed station.

6.2.2.4. Substrate Colonization Studies

In the Trail River, 29 and 57 days after installation, artificial substrates dipped in Norman Wells crude were covered with a luxuriant growth of algae as compared to the controls. Similar observations were made in Caribou Bar Creek. In the Liard River and the East Channel of the Mackenzie Delta, control and oil-dipped artificial substrates remained similar in appearance and had little or no apparent algal growth. Quite conceivably current speed, silt load, and light penetration on each river were the major influencing factors in this regard.

The rate of loss of oil on rocks in oil-dipped artificial substrates at installation and at subsequent removal dates are shown in the following table.

<u>River</u>	<u>No. days after installation</u>	<u>% of oil remaining on rocks</u>
Trail	0	100.0
	29	100.0
	57	33.9
Liard	0	100.0
	36	4.0.

These values are usually based on three samples. Artificial substrates were installed in the Trail River on July 14, 1972. The Liard River artificial substrates were installed August 8, 1972. Initial mean concentrations of oil on rocks in artificial substrates in the Trail and Liard Rivers were 1 and 0.9 mg oil/g rock. Twenty-nine days after treatment, rocks in the Trail River retained approximately the same concentration of oil. In the Liard, however,

Fig. 9 Map of Yellowknife Bay showing sampling sites



Table XII. Nos. of Invertebrates/m² collected in Yellowknife Bay

	<u>0.5 m</u>		<u>2.0 m</u>		<u>4.75 m</u>	
	<u>Disturbed</u>	<u>Undisturbed</u>	<u>Disturbed</u>	<u>Undisturbed</u>	<u>Disturbed</u>	<u>Undisturbed</u>
Oligochaeta	258	43	775	672	155	586
Gastropoda	186	284	158	545	560	2639
Pelecypoda	230	-	57	344	198	1550
Amphipoda	-	28	229	5124	4792	6773
Ostracoda	-	4	71	158	-	-
Trichoptera	-	14	-	28	14	86
Chironomidae	402	172	416	1950	573	603
Ceratopogonidae	28	-	-	57	-	-
Tripulidae	-	28	-	-	-	-
Coleoptera	-	28	-	-	-	-
Acarina	14	-	-	57	86	142
Total/m ²	1118	611	1706	8935	6378	12379

96% of the oil had been lost after 36 days. After 57 days in the Trail River, approximately 66% of the oil had been lost. The difference in oil retention between the two artificial substrate experiments in the two rivers appears to be related to rates of discharge and suspended sediment transport. At this point, it is too early to draw inferences from the relationships between oil concentrations and invertebrate populations per artificial substrate.

Distinct differences in the occurrence of taxa expressed as per cent of the total numbers of organisms exist between oil-dipped and non-dipped artificial substrates in the Trail River (see Figs. 10A and B). Essentially, the results for the two dates are similar. Actual per cent occurrences changed due to seasonal life histories of the various taxa, but relationships of dominance did not. For example, note the dramatic increase in per cent occurrence of Chironomidae in the September data. Note, however, that a higher per cent was present on the oil-dipped substrates for both dates. The Ephemeroptera, Trichoptera, and Gastropoda were present as a higher per cent of the total fauna in the control substrates. The Chironomidae and Oligochaeta were present in greater per cent on the oil-dipped substrates. The Simuliidae and Empididae showed an initial higher occurrence on the oil-dipped substrates. By September empidid larvae were present on both oil-dipped and control substrates in approximately equal proportions, however simuliid larvae were more abundant on the oil-dipped substrates. Hydracarina were always present in higher numbers at control Station 2. Total numbers of organisms per substrate for September 7, 1972 were higher for oil-dipped than non-dipped substrates (see Figs. 10A and B). Diversity, as defined by Shannon-Weaver diversity index derived from information theory (see App. 1V, p. 14), is highest when an equitable distribution of numbers exists among the taxa present, and lowest when numbers are concentrated in one or a few taxa. Over three-quarters of the total numbers of organisms on the oil-dipped substrates were concentrated in just three taxa (Chironomidae, Oligochaeta and Simuliidae) in the August sampling number of organisms. The control substrates, on the other hand, show a more equitable distribution of numbers among taxa relative to the oil-dipped ones. Therefore, the oil-dipped artificial substrated supported larger numbers of organisms, but a lower diversity of organisms, compared to the control.

Differences in occurrence of taxa existed between oil-dipped and non-dipped artificial substrates in Caribou Bar Creek among the Nematoda, Plecoptera, Empididae, and Chironomidae (see Fig. 11). Less distinct differences appeared in the Trichoptera and Hydracarina. Ephemeroptera and Tipulidae showed no clear preference for either substrate. Hydracarina, Nematoda, Trichoptera and Chironomidae clearly favoured the oil-dipped substrate while Plecoptera and Empididae favoured the controls. Total number of organisms and mean number per substrate were almost the same.

The results are compared to the results from the Trail River, a river of similar size. Considering only the major taxa (i.e. greater than 2% occurrence), Plecoptera, Ephemeroptera, Trichoptera, Gastropoda, Chironomidae and Oligochaeta were present in the Trail River artificial substrate samplers in the July 14 to September 7 period while the Caribou Bar Creek samplers collected Nematoda, Plecoptera, Trichoptera, and Chironomidae. Of the major taxa common to both rivers, the Plecoptera were reduced in occurrence on the oil-dipped substrates in both rivers. Chironomidae showed a higher



Figure 10

Percent occurrence of taxa on; and total numbers of organisms and mean number per artificial substrate colonizing, oil-dipped (1 & 2) artificial substrates in the Trail River

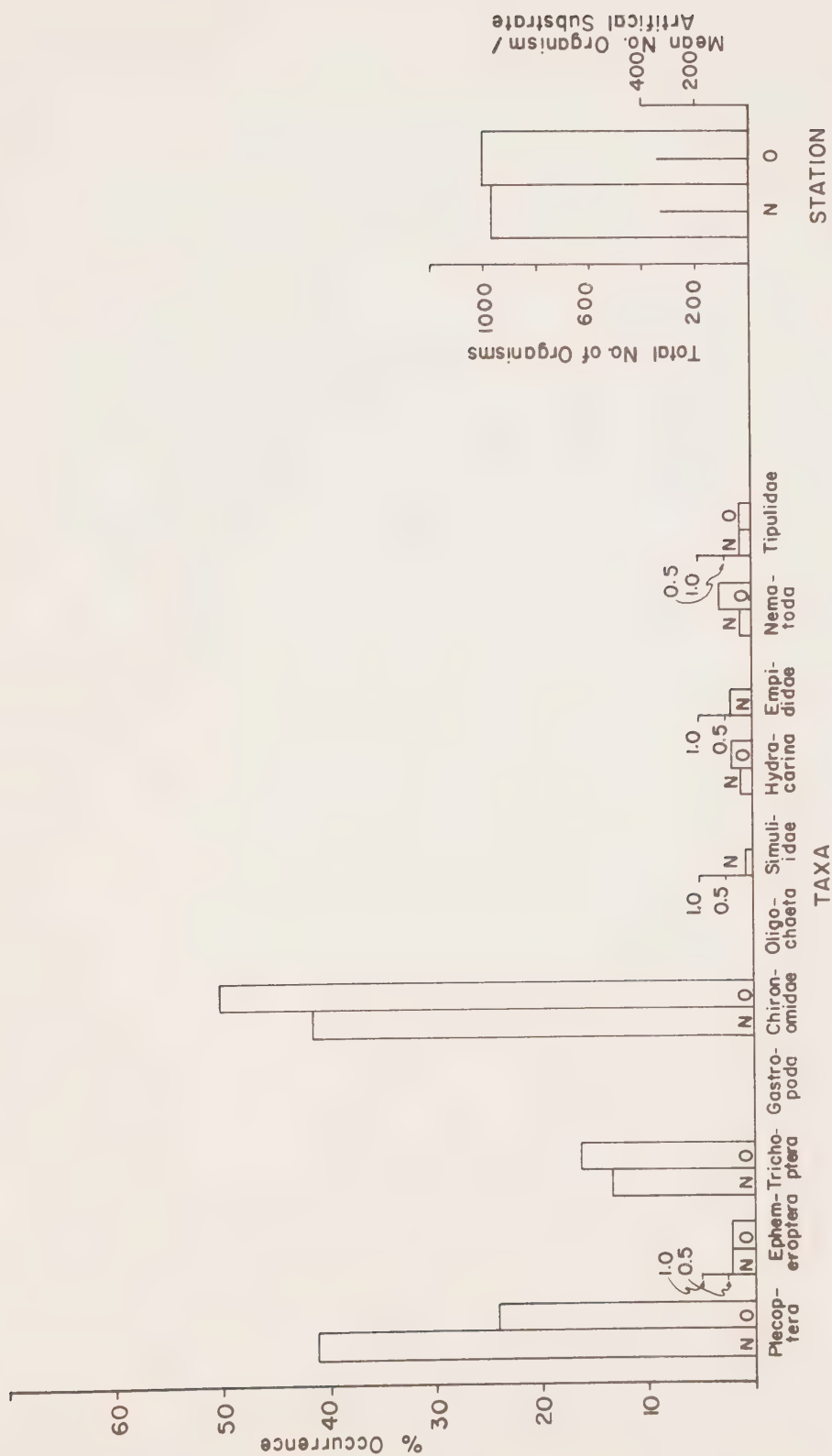


Figure 11: Percent occurrence of taxa on; and total numbers of organisms and mean number per artificial substrate colonizing, oil-dipped (O) and non-dipped (N) artificial substrates in Caribou Bar Creek, August 17, 1972 to September 14, 1972

occurrence on oil-dipped substrates in both rivers. Trichoptera had a higher occurrence on the non-dipped substrates in the Trail River but were in greater abundance on the oil-dipped substrates in Caribou Bar Creek. The mean numbers of organisms per artificial substrate was very different in the two rivers.

Results from the Liard River experiment are shown in Figs.12A and B. Preference for oil-dipped versus non-dipped substrates were reversed from the August to September and August to October sets. The magnitude of the differences in percent occurrences for most of the taxa in both sets of artificial substrate samplers was not significant (except for the Plecoptera and Simuliidae in the August to October set). The reversal of percent occurrences was probably due to life history changes. Note, however, that the total number of organisms and mean number per artificial substrate were higher on non-dipped than on oil-dipped artificial substrates.

The artificial substrates suspended in the East Channel of the Mackenzie Delta at Inuvik (EC10), were identical to those used in the Liard and Trail Rivers and Caribou Bar Creek. They did not collect large amounts of algae and organic debris and in this respect approximate the performance of the Liard samplers. The taxa common to both sets of samples from the East Channel show similar trends (see Fig.13A and B). Plecoptera, Ephemeroptera, and Chironomidae had higher percent occurrences on oil-dipped artificial substrates; Trichoptera favoured the non-dipped substrates. In the July to August experiment, Simuliidae, Hirudinea, and Hydracarina favoured non-dipped substrates while Oligochaeta preferred the oil-dipped substrate. Fewer taxa were present on the July to September set of samplers. Total numbers and mean number of organisms per substrate were over twice as great on non-dipped than on oil-dipped substrates (Fig.13A and B). Total numbers of organisms on artificial substrates declined in the Liard River and Delta Channels with the approach of fall and ice formation. The dominant species on EC10 substrates in both August and September were Trichopteran larvae of the genera Neureclipsis and Hydropsyche (Figs.13A and B). These species are net-spinning caddis larvae and almost all of the retention of debris on the substrates was a result of their mucus nets filling up the interstices of the rocks.

Artificial substrates in the East Channel under early Winter ice (November-December, 1972) collected very small numbers of organisms of only two taxa: chironomid larvae and Amphipoda (Figs.14A and B). It is important to note that amphipods were not collected at all by artificial substrates during the open-water season. Numbers of organisms and taxa of sub-ice drift are shown in Fig.14C. These data supplement those yielded by the artificial substrates and clearly indicate the presence of very low numbers of organisms from five taxa, only two of which appeared on the artificial substrates. The amphipods (all of which were male Pontoporeia affinis) occurred only on oiled substrates, and most were dead. It appeared that the oiled substrate acted as a "sticky trap" to capture these environmentally sensitive amphipods.

6.2.2.5. Effect of Silt on the Zoobenthos of the Mackenzie and Porcupine River Systems

Numbers of organisms per m² for Mackenzie River tributaries and the Northern Yukon drainage are presented in Tables XIII and XIV respectively. These data were gathered in August-September, 1971. Upper and lower, clear and turbid sections of streams were separated. In addition, using data from wherever three Surber samples were available and Secchi visibility measurements



Figure 12

Percent occurrence of taxa on; and total numbers of organisms and mean number per artificial substrate colonizing, oil-dipped (O) and non-dipped (N) artificial substrates in the Liard River

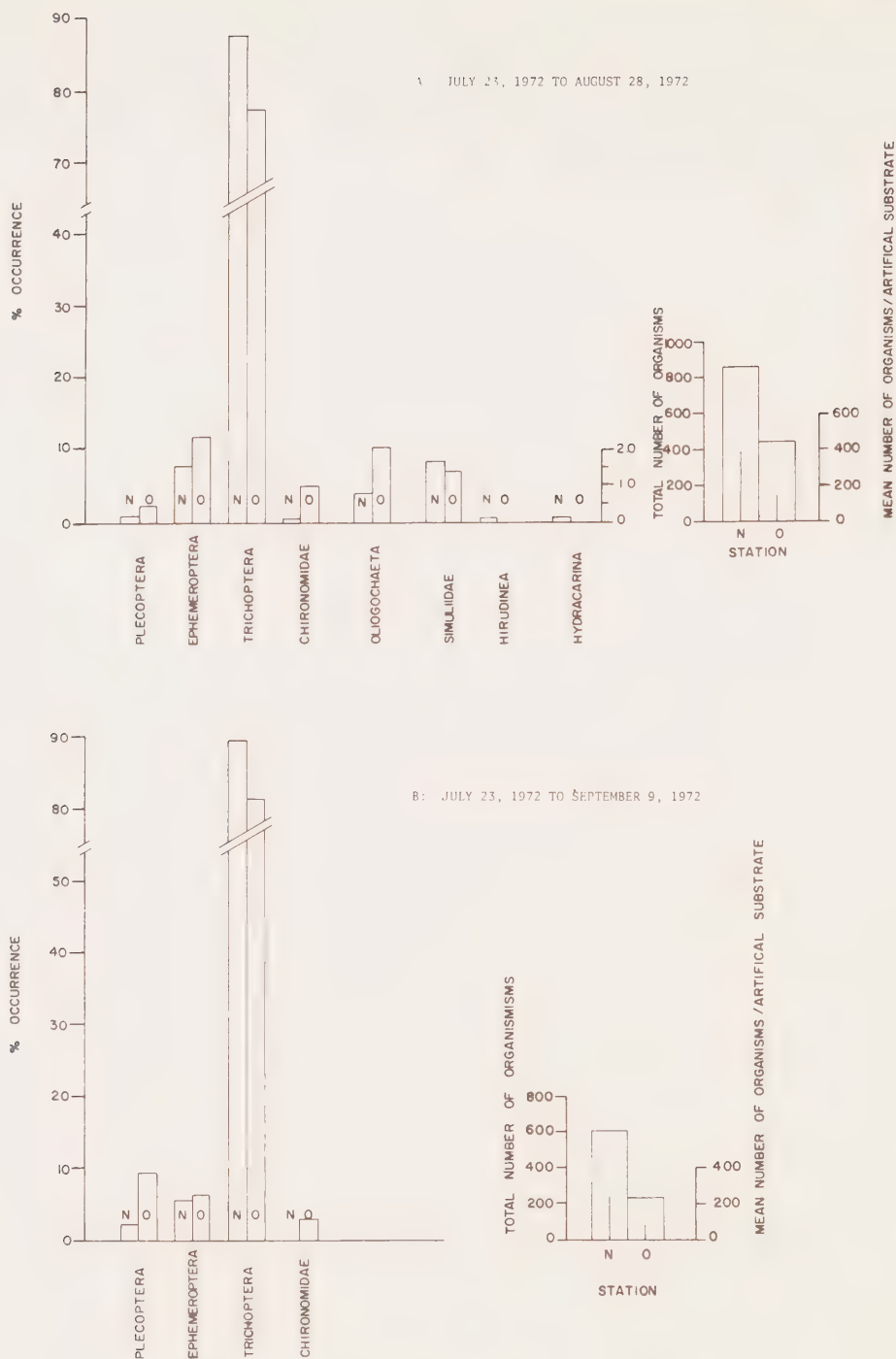


Figure 13:

Percent occurrence of taxa on; and total numbers of organisms and mean number per artificial substrate colonizing, oil-dipped (O) and non-dipped (N) artificial substrates in the East Channel at EC10

Fig. 14A. Percent occurrence of taxa on artificial substrates dipped (0) and not dipped (N) in Norman Wells crude oil and suspended in the East Channel from Nov. 21/72 to Dec. 12/72 at EC10.

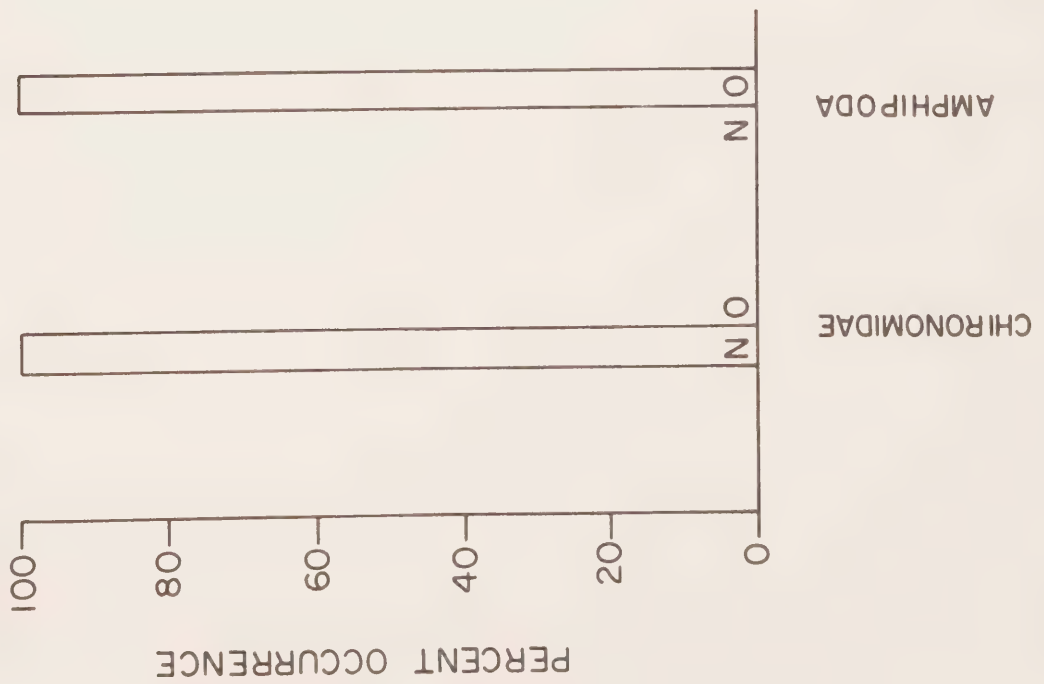


Fig. 14B. Mean number of organisms per artificial substrate and total numbers of organisms collected by oil-dipped (0) and clean (N) artificial substrates suspended in the East Channel from Nov. 21/72 to Dec. 12/72.

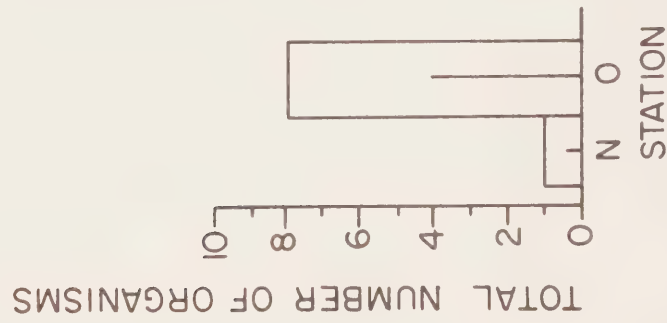


Fig. 14C. Total numbers of benthic invertebrates comprising sub-ice drift at EC10 Nov. 21/72 to Dec. 12/72.

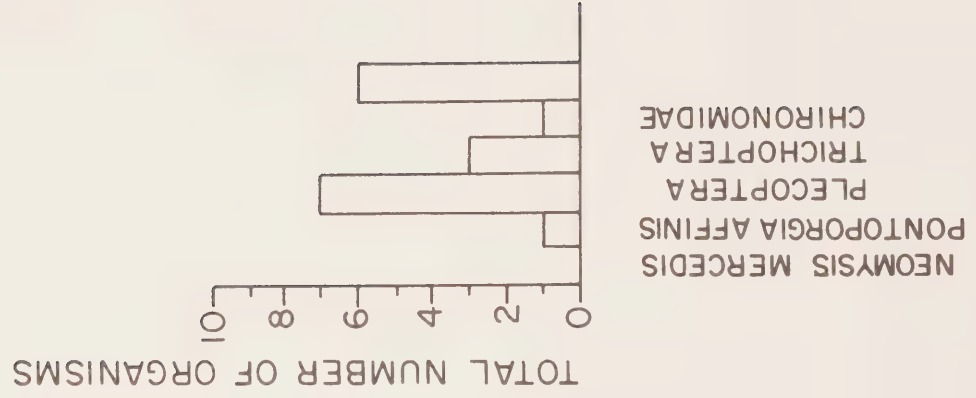


Table XIII Numbers of benthic organisms per m², taken with a Surber Sampler, in the upper and lower reaches of several Northern Mackenzie tributaries (Peel, Arctic Red and Rampart River drainages), August and September, 1971.

	CLEAR UPPER	MUDDY UPPER	CLEAR LOWER	MUDDY LOWER
Stony Creek	43 129 161		75 32 43	
Vittrekwa River	323 205 32	21 32 54	193 388 269	97 43 54 32 32 21 21 11 11
Road River	139 215 151 463 689 463			
Trail River	226 172 54			
Rampart River	969 549 527	32 11 0		
Caribou River		0 11 21		65 86 21
Mountain Creek		11 108 54		
Cranswick River			43 172 118	

Table XIII continued

	CLEAR UPPER	MUDDY UPPER	CLEAR LOWER	MUDDY LOWER
Bonnet Plume			248 140 344	
MEAN	30.6	30	172	38

Table XIV. Numbers of benthic organisms per m², taken with a Surber Sampler, in upper and lower reaches of rivers in the Yukon drainage, August and September, 1971.

	CLEAR UPPER	MUDDY UPPER	CLEAR LOWER	MUDDY LOWER
Driftwood	140 861 1173		75 86 527	
Firth	182 205 140		248 129 65	
Old Crow	2314 2185 1647			248 290 248
Bell River	1324 1152 2314			75 65 21
Eagle River		86 21 0		
Porcupine River			312 43 226	54 43 97 183 215 108
Blow River				21 21 0
Babbage River	904 1378 506		743 474 291	
MEAN	1152	57	254	113

had been taken, the regression equation for the relationship between density (numbers/m²) and Secchi depth was calculated.

This equation was:

$$\hat{Y} = 36.15 + 1.114X \quad (1)$$

and for Norman Wells area data:

$$\hat{Y} = 24.19 + 1.575X \quad (2)$$

(where $Y = \#/m^2$ zoobenthos
 $X = \text{Secchi visibility in cm.}$)

From the Fort Simpson area, the samples from five rivers were tabulated with mean suspended sediment weights. The results (Table XV) indicate that no relationship exists between the mean No./m² of zoobenthos and increased amounts of suspended sediment probably because of the small range of seston concentrations.

The annual variation in profundal benthos density in clear and turbid Mackenzie Delta lakes is shown in Table XVI. The clear lakes had 45-98 times the density of the profundal zoobenthos of silty lakes. Both silty lakes had similar densities of profundal zoobenthos. The clear lakes suffered a drastic reduction in numbers of profundal zoobenthos after Delta flooding and intrusion of silt-laden water. In one case the density was reduced by a factor of twenty-five, in the other it was halved. The silty lakes showed an increase in density at this time. There was also a difference between taxon diversity (Table XVII) and species diversity (Appendix XV) in the two types of lake. Clear lakes supported almost five times as many taxa as silty lakes. Of these, thirty-six occurred exclusively in clear lakes, five occurred exclusively in silty lakes and four co-occurred in silty and clear lakes (Appendix XV).

The regression equation for the Mackenzie Delta relationship between suspended sediments and zoobenthos density is:

$$\log y = 3.71 - 0.50 \log x. \quad (3)$$

A similar relationship was established for rivers and streams along the mainstem Mackenzie. This is expressed by the following equation:

$$\log y = 3.05 - 0.44 \log x. \quad (4)$$

In both equations, $x = \text{suspended sediment (mg./l)}$, and $y = \text{zoobenthos density (\#/m}^2 \text{ and \#/artificial substrate respectively)}$.

From both of these relationships it appeared that a sharp increase in zoobenthos density occurred in water bodies with suspended sediment levels less than 10 - 15 mg/l.

Between August 13 and 15, 1972, a natural mudslide occurred on Caribou Bar Creek. This section of the creek was then subjected to a more intensive study. The first set of samples were taken on August 15, 1972. Secchi visibility above the slide was greater than 1.0 m, and below the slide was 0.52 m. Corresponding suspended sediment values were 3.82 mg/l above and 10.6 mg/l below the mudslide. The mean of three Surber samples above and below the slide, converted to zoobenthos/m² are shown in Table XVIII. There was a 70% reduction in total numbers of benthic organisms present. Treating the same data as

Table XV. Relationship between zoobenthos abundance and suspended sediment concentrations in the Fort Simpson Region.

Location	Date of sampling	n	Mean No. per meter ²	Mean suspended sediment, mg/l	Dates for suspended sediment samples	
	<u>day month</u>				<u>day mth</u>	<u>day mth</u>
Harris River	30/08	3	59,209.1	0.521	-	30/08
Trail River	16/09	6	6,086.9	1.05	8/09	21/09
Martin River	15/09	3	20,311.7	2.47	7/08	9/09
Jean Marie River	8/09	5	4,038.8	4.28	8/08	8/09
Rabbitsskin River	8/09	2	4,606.0	7.06	8/08	8/08

Table XVI. Relationship between zoobenthos abundance in clear and turbid lakes before and after spring flooding in the Mackenzie Delta.

Zoobenthos abundance (#/m ²)				
Clear			Turbid	
Date	Lake 5	Lake 7	Lake 1	Lake 3
August 1971	17976	28,906	336	448
December 1971			308	
March 1972			112	
	(Delta in flood)			
June 1972	9380	2,016	406	1750
July 1972	9352			420
August 1972		7,854	182	

Table XVII. Numbers of profundal benthos species in silty and clear lakes in the Mackenzie Delta.

<u>Taxon</u>	<u>Clear (5 and 7)</u>	<u>Silty (1 and 3)</u>
Chironomidae	13	4
Ceratopogonidae	1	1
Chaoboridae	1	0
Hemiptera	1	0
Ephemeroptera	0	0
Trichoptera	2	0
Nematoda	2	1
Oligochaeta	2	2
Ostracoda	8	1
Amphipoda	1	1
Gastropoda	11	1
Pelecypoda	7	2
	50	13

Table XVIII. Mean numbers of organisms per m², taken with a Surber Sampler, above and below the Caribou Bar Creek mudslide.

	<u>15 08 72</u>		<u>31 08 72</u>	
	<u>Undisturbed</u>	<u>Disturbed</u>	<u>Undisturbed</u>	<u>Disturbed</u>
Nematoda	0	7	47	0
Oligochaeta	0	11	29	54
Plecoptera	0	0	61	43
Ephemeroptera	61	11	0	0
Trichoptera	32	0	183	50
Tipulidae	0	0	0	0
Simuliidae	0	0	21	0
Chironomidae	18	14	1245	308
Ceratopogonidae	0	0	0	7
Empididae	0	0	0	0
Rhagionidae	0	0	0	0
Acarina	230	61	104	36
Total/m ²	341	104	1697	498

percent of total shows a shift in zoobenthos dominance from Trichoptera to Chironomidae. On August 31 the mudslide was still active, and Secchi visibility below the disturbance was reduced to 0.25 m. The numbers had increased both above and below the slide, but numbers of zoobenthos in the disturbed area were still 70% below the undisturbed area. The taxon composition was similar in the two areas (Fig. 15).

6.2.2.6. Fort Simpson Highway Impact Studies

Martin River Crossing

During the summer of 1972 construction was begun on the Mackenzie Highway north from Fort Simpson. The first major river crossed was the Martin River (see Figs. 16 and 17). To evaluate the effects of construction, detailed physical measurements, water samples, and phyto- and zoobenthos samples were taken.

There was an indication that the stations downstream from the highway crossing carried a slightly higher suspended sediment load than the upstream, control station. No differences were discernible in other physical and chemical measurements done in areas upstream and downstream of the crossing. A lag period is likely to occur before constructional effects are evident in the water.

No change was detected in zoobenthos sampled downstream from the crossing. The data are presented in detail in Appendix IV.

The effect of a Nodwell vehicle crossing on invertebrate drift is shown in Fig. 18. The crossing increased the total number of invertebrates in the drift and the disturbance continued in reduced form after the Nodwell had crossed. Also, more detritus was captured by the downstream nets. While the increase in drift and observed detritus was not of catastrophic proportion, repeated disturbances of similar magnitude could have considerable impact on an aquatic system.

Poplar River Crossing

As part of the Fort Simpson to Fort Nelson highway, a bi-culverted crossing was made of the Poplar River about one mile upstream of its confluence with the Liard River. The approaches to the crossing were levelled and the resulting fill used for the roadway across the river. A coffer dam was constructed from river substrate sixty meters upstream of the crossing to divert the river while the crossing was installed. The dam was never fully removed. Rather an opening of about 3 m was made in it (see Fig. 19). The oval culverts have a maximum diameter of about five meters. The width of the river bed at the point of crossing is about 150 m (see Fig. 19). Because the crossing was built in November of 1971, the fill used was composed of frozen soil. With the advent of warmer weather, this thawed and parts of the crossing have started to subside.

In the spring of 1972, Fisheries Service personnel found grayling fry in abundance below the crossing but none above (R. Porter, personal communication). This implied that spawning migration of grayling had been blocked by the crossing. To assess the impact of the crossing on benthos (in particular, drifting organisms) a sampling trip was made to the Poplar River on

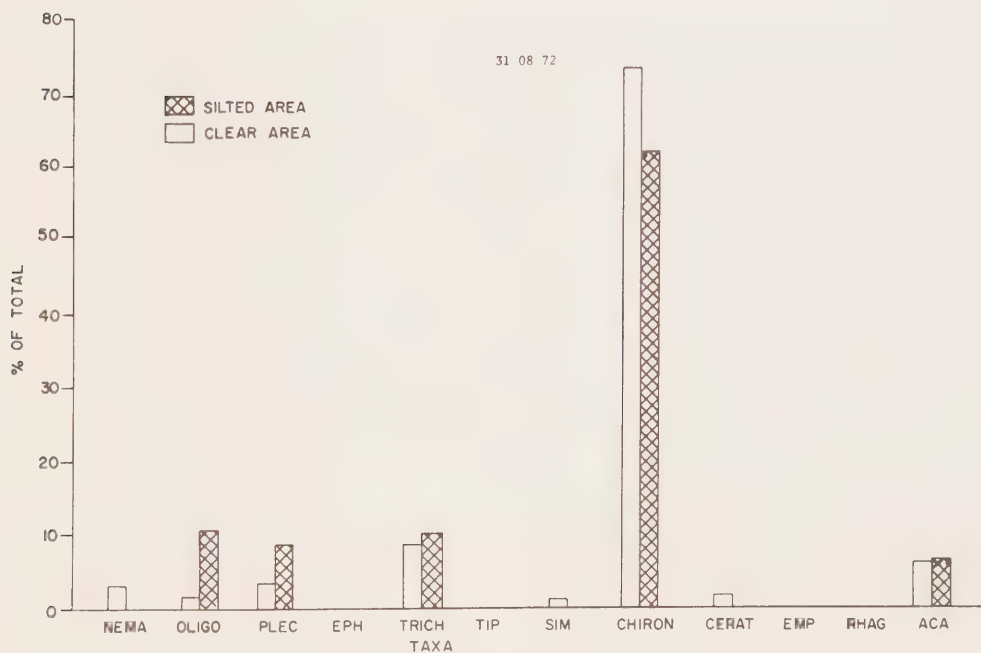
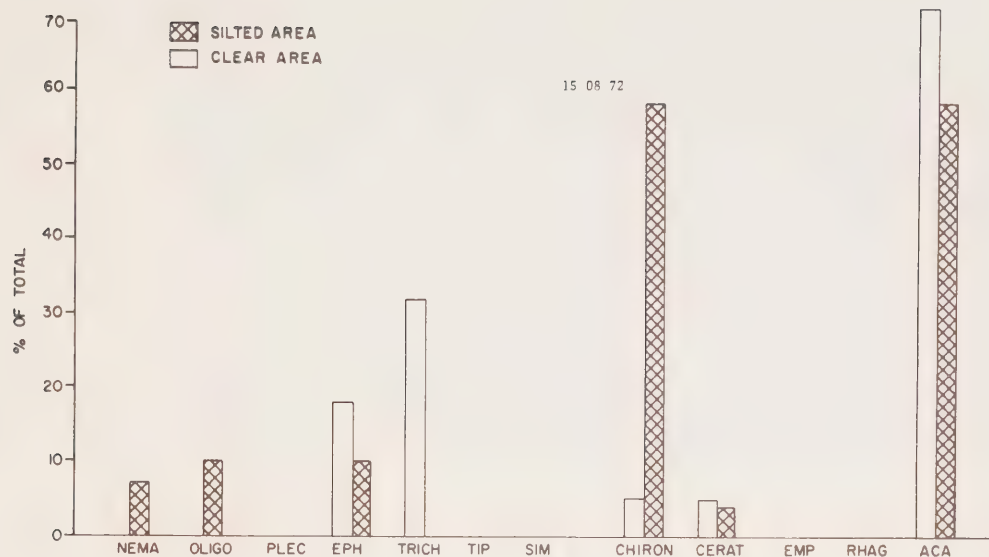


Figure 15: Composition of mud slide area zoobenthos



Figure 16: Mackenzie Highway crossing, Martin River, N. W. T. Looking west.
Riffle area used by equipment for crossing. A: August 18, 1972.
B: September 13, 1972.



Figure 17: Mackenzie Highway crossing, Martin River, N. W. T. Looking west.
A: July 17, 1972. Seven and a half meter survey slash. B: September 13, 1972. Cleared 30 meter right of way. Note inverted "V"-shaped slump at bottom of hill.

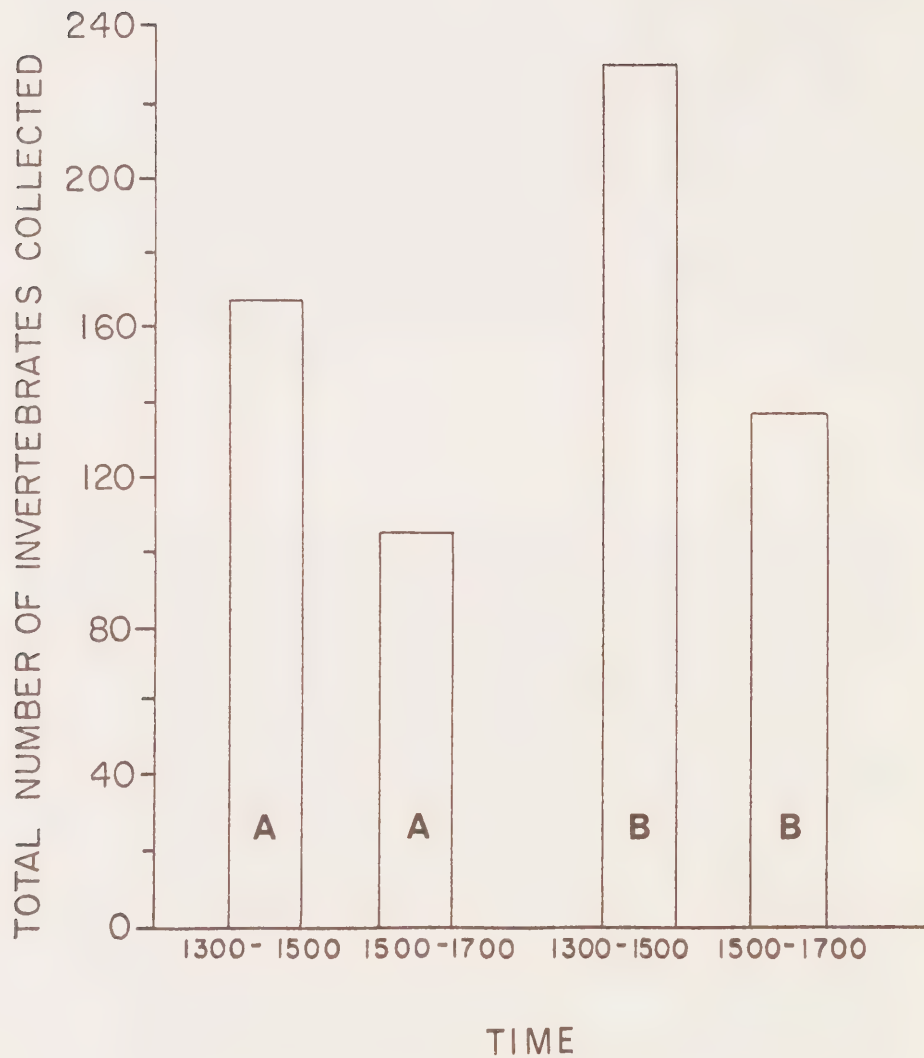


Figure 18: The effect of a Nodwell crossing (1300-1500 hrs) on the drift of invertebrates in the Martin River upstream (A) and downstream (B) of the crossing on August 18, 1972.



Figure 19: Poplar River, N.W.T. September 26, 1972. A: Looking upstream from top of culvert crossing. Note coffer dam about 2/3 the way up the picture. B: Looking downstream from top of culvert crossing. Note the debris accumulated at the downstream end of the pool.

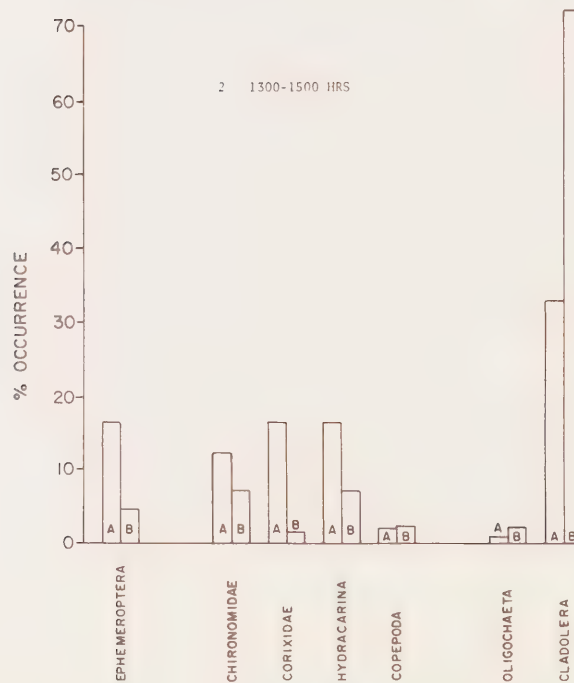
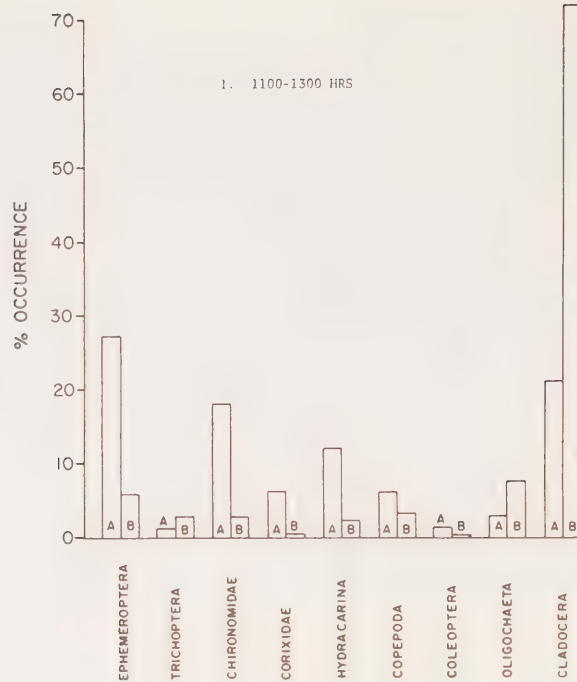


Figure 20: Percent occurrence of drifting invertebrates upstream (A) and downstream (B) of the Poplar River Road crossing on September 26, 1972.

September 26, 1972. At that time both ends of the southern culvert were level with the substrate. Water velocities at the upstream and downstream ends of the culvert were 0.76 m/sec and 1.1 m/sec respectively. The upstream end of the northern culvert was level with the substrate, but there was a 1.2 m drop between the culvert tip and the stream substrate at the downstream end. Water velocity at the upstream end was 0.765 m/sec. At the downstream end, the velocity was too fast to be measured by our flow meter but was estimated to be 2.5 m/sec. Pools were formed at upstream and downstream ends of the culverts (see Figs.19a. and b) and trees littered the downstream pool, especially in the vicinity of the southern culvert (see Fig.19b). Any fall migrations of fish through the already shallow water would be effectively blocked by the trees and, in the northern culvert, by the four-foot drop and swift current.

An examination of benthic invertebrates in the drift above and below the culverted road crossing was made. Analysis of the samples clearly shows a difference between upstream (A) and downstream (B) stations (see Figs.20 a and b). The greater number of Oligochaeta and Cladocera at B reflects the influence of the pool. Note that per cent occurrence of taxa at A is more evenly distributed than at B. Diversity of the drifting organisms (as measured by the Shannon-Weaver Index) would be greater at A. Lower diversity is usually characteristic of a disturbed area.

7. Discussion

7.1. Ecology of the Mackenzie-Porcupine systems with special emphasis on the effects of suspended sediment.

Rates of transport of suspended sediments in the Mackenzie and Peel River watersheds are compared to data from other large rivers that have and have not been disturbed by technological development (Table XIX). The Mackenzie River data do not include bed load estimates, are based on a less than satisfactory sampling frequency, and should therefore be viewed as minimal estimates. Mackenzie watershed rivers draining mountainous terrain tended to carry more sediments than low relief watersheds (Fig.1, Appendix X), as was found by Gibbs (1967a) for the Amazon River, and Depetris & Griffin (1968) for the Rio de la Plata. Despite low annual precipitation, and the watersheds' being frozen for 5-7 months of the year, some Mackenzie watersheds (Arctic Red, Peel, Liard, South Nahanni) transported sediments in the range of more disturbed watersheds of southerly latitude (Missouri, Mississippi). Great Bear and Willowlake Rivers have low relief and lakes (which act as sediment traps) in their drainage areas, and were among the lowest values for rates of transport of suspended sediments in Table XIX. The watersheds most comparable climatically to the Mackenzie are the Yenisei and Ob Rivers of Subarctic and Arctic USSR, which have suspended sediment transport rates an order of magnitude less than most of the Mackenzie watershed estimates given here.

It is thus obvious that some Mackenzie watersheds carried relatively large amounts of suspended sediment in a short period of time compared to temperate and tropical rivers. Most of the annual sediment load was transported in the months of June and July in the Mackenzie watersheds. The very turbid rivers often increased in transparency by an order of magnitude in Fall (e.g., Redstone River Secchi visibility in Spring was 2 cm, but increased to 40 cm in Fall, allowing growth of algae on stones in the river bed). This seasonal distribution of sediment transport was even more dramatic in the case of the smaller rivers (Willowlake, Martin, Harris, Rabbitskin, Jean Marie, Caribou Bar Creek, for which the data are not complete) where up to 90% of the estimated annual suspended sediment was carried by high discharges of several weeks duration in late May and early June.

Rates of transport of suspended sediment can be considered as a rate of transport of potential food material, or as a deterrent to aquatic organisms. With increasing suspended sediment, PC and PP usually increased, but PN showed little trend (Figs.21,22,23). Little relationship was found between dissolved nutrients and suspended sediments. In extreme cases of high suspended sediment transport rates, most of the suspended sediment was composed of inorganic clays and silts. These inorganic materials are probably deterrents to most aquatic organisms, in that increased silt loads dilute their food resource (organic material), alter their substrate on the stream bed, and reduce light penetration for plant growth. The reactivity of most shore and bank inorganic sediments is likely to be low, since these sediments were usually glacial, fluvial, or lacustrine in origin, and have been previously transported by freshwater. These clays usually have cation exchange capacities from 10-50 meq/100 g, and are probably saturated with Ca, Mg, and Na. Most of the minerals in suspension are relatively unweathered, and are physically abraded particles of the source material which have had

Table XIX Estimated annual rates of transport of suspended sediments from Mackenzie River watersheds, and other large river data. Q_a = annual discharge in km^3 , A_d = drainage area in thousands of km^2 , ROT (SS) = rate of transport of suspended sediment per unit watershed area, in metric tons $\text{km}^{-2} \text{yr}^{-1}$.

RIVER	Q_a	A_d	ROT (SS)	Disturbance	Reference
———— North America ————					
Peel	22.0	70.7	95.9	no	this study
Arctic Red	4.94	15.1	132.	no	this study
Mackenzie at Norman Wells	247	1570	89.2	no	this study
Great Bear	18	146	0.017	no	this study
Willowlake	1.44	21.6	1.14	no	this study
Liard at Ft. Liard	53.3	222	27.1	no	this study
South Nahanni at Clausen Creek	11.3	33.4	49.1	no	this study
Columbia at Trail, B.C.	25.7	88.1	12.6	yes	Water Survey, 1967
Frazer at Hope, B.C.	34.7	203	114	yes	Water Survey, 1967
Peace at Peace Point	16.1	293	164	little	Water Survey, 1967
Saskatchewan at the Pas	20.0	324	~5	little	Water Survey, 1967
Red at Lockport	10.0	288	8-12	agriculture	Water Survey, 1967
Missouri	61.9	1370	159	agriculture	Holeman, 1968
Mississippi	563	3220	64-97	agriculture	Gibbs, 1967a & Holeman, 1968
Los Angeles	0.119	1.99	222	yes	Rodolfo, 1970
San Gabriel	0.021	1.51	119	yes	Rodolfo, 1970
———— Europe ————					
Volga	253	1350	14.0	yes	Holeman, 1968
Danube	195	816	23.8	yes	Holeman, 1968
———— Africa & South America ————					
Zaire (Congo)	1250	4010	8.90	little	Gibbs, 1967
Niger	100	1110	9.00	little	Grove, 1972
Amazon	5500	6300	79.0	no	Gibbs, 1967
Mountainous Tributaries of the Amazon	~320	~400	250-300	no	Gibbs, 1967
———— Asia ————					
Yenisei	548	2470	4.21	no	Holeman, 1968
Ob	394	2447	5.96	no	Holeman, 1968
Ganges	445	1060	1400	yes	Holeman, 1968
Yellow	47.3	715	2640	yes	Holeman, 1968
Ching	1.79	57.0	7180	yes	Holeman, 1968

little time to react chemically with the solution. Soils rich in organic matter, however, would be quite reactive in stream or lake water (Baker, 1973). In addition to depleting the water of O_2 , organic soils will tend to release and absorb major and minor elements depending largely upon changes in pH and ionic strength in the solution phase. In uncontaminated areas free of heavy metal deposits, this effect is not likely to be of importance. With industrial development, however, soils and vegetation are likely to be chemically altered by waste products, insecticides and pesticides.

The whole study area suffers from a general lack of background information concerning the abundance, distribution and composition of the zoobenthic fauna. As a result of the initial survey it was possible to assess relative abundances and to make gross generalizations concerning the distribution and composition of the zoobenthos. Life-history patterns of certain species are also beginning to emerge. This baseline information will be available, at least for the areas of intensive study, at the time of completion of the project.

At present it would seem that the aquatic ecosystems within the study area are impoverished by comparison with comparable systems in more southerly latitudes in terms of faunal density and diversity. The generalized trend of reduction in complexity of food-webs with increasing northerly latitude is in evidence, although all of the systems studied are rich by comparison with those of the high Arctic.

In the study of the Mackenzie mainstem from Fort Simpson to Arctic Red River the Plecoptera and Chironomidae predominated over all other taxa in the rivers of the study. The Chironomidae were the dominant fauna in clear streams particularly of the south (e.g., Jean Marie, 81%). They were, however, replaced in dominance by the Plecoptera in the Norman Wells area but regained dominance in the north. In turbid rivers, e.g., Loon Creek and Mackenzie River at Point Separation stations I and II, Plecoptera were the dominant groups. The Oligochaeta, normally associated with turbid situations, did not show a major increase in the turbid rivers studied. These occurrences may be a reflection not so much of turbidity but rather of current speed which would keep the substrate clear of depositional silt, as was found to be the case with Simulium larvae (Wu, 1931). Densities of zoobenthos in the Peel and Arctic Red River systems were very low. This is consistent with our observations in other turbid rivers. Our sampling occurred late in the open water season of 1971, so densities reported may be lower than earlier in the season. Many of the tributaries of the Peel River are normally clear, according to the inhabitants of local settlements. Consequently the presence of large amounts of silt may indicate that these systems were in some way disturbed and therefore represent an abnormal situation. Most of the stations sampled had silt covered rocky substrates. Such conditions are not conducive to colonization of zoobenthos of the types characteristic of the area. The absence of Trichoptera was a good indication of this. The few sample localities where Trichoptera were found were all high altitude tributaries, which at the time were running quite clear, i.e., free of high concentrations of suspended sediments.

The conditions encountered in the Caribou River should be taken as a warning of what a disturbance in the watershed (in this case a fire) could do to a river system. In the disturbed areas water was running down the slope in

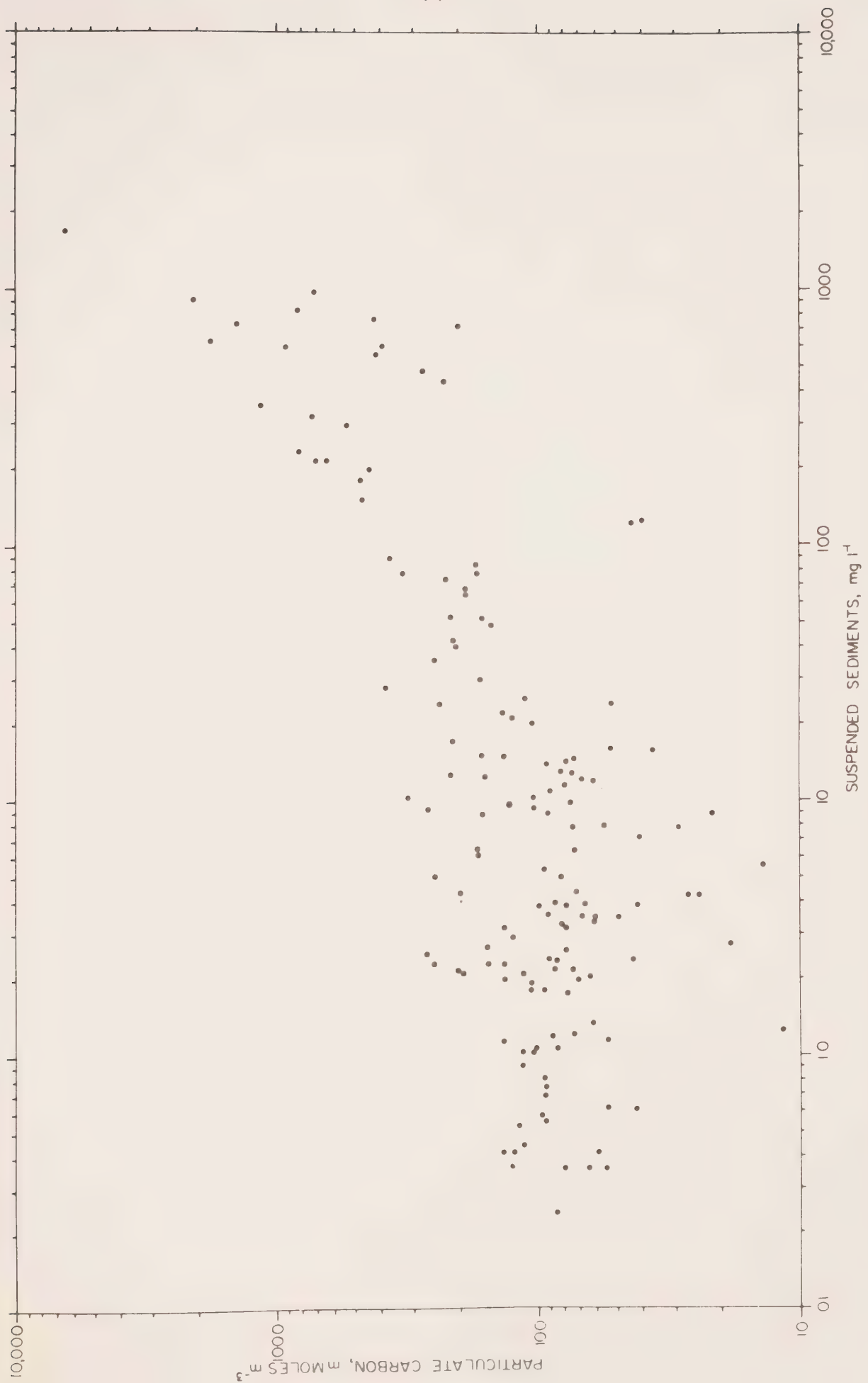


Figure 21: Relationship between concentrations of particulate carbon and total suspended sediment in N.W.T. and Y.T. rivers and streams during 1971-72.

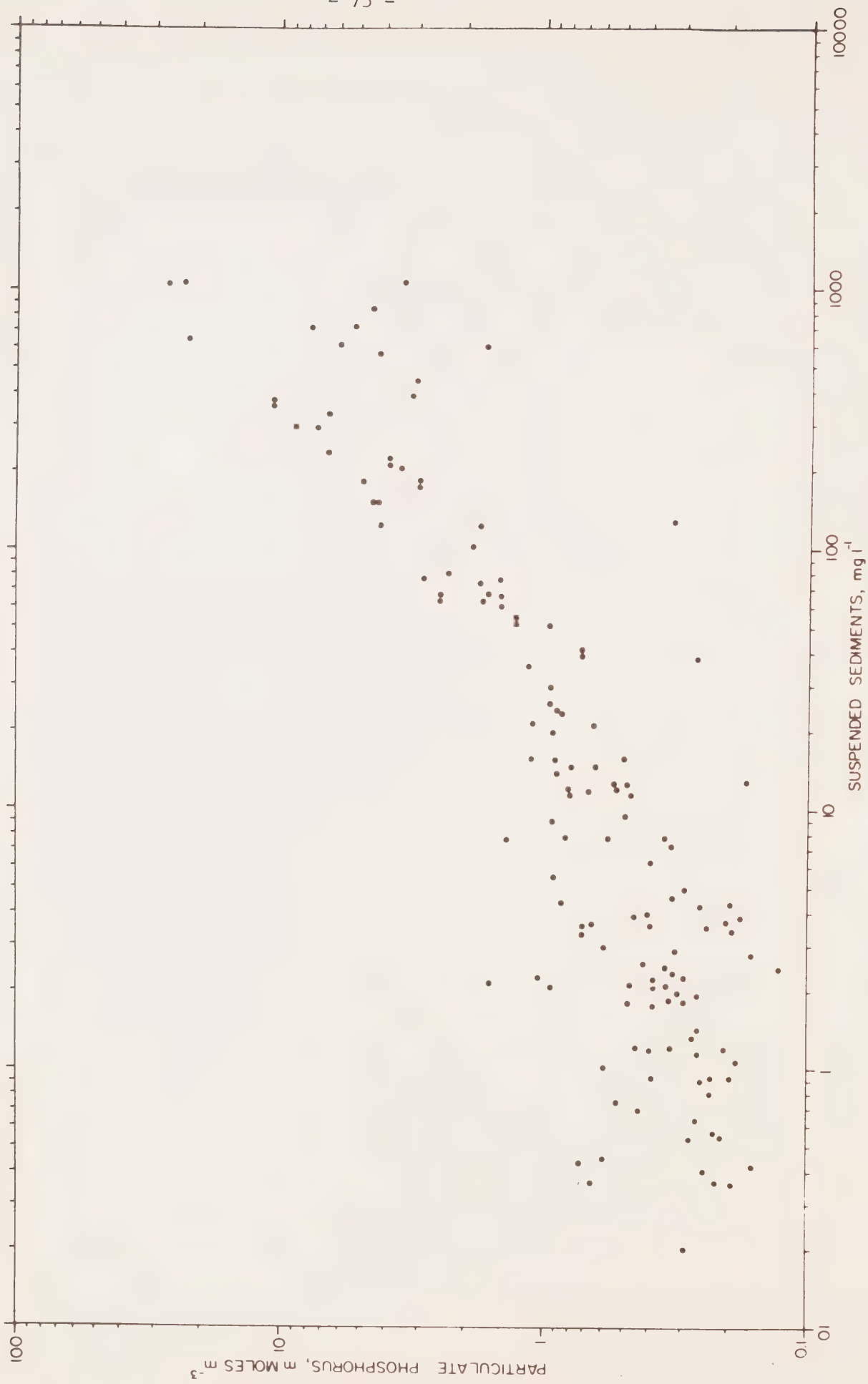


Figure 22: Relation between concentrations of particulate phosphorus and total suspended sediment in N.W.T. and Y.T. rivers and streams during 1971-72.

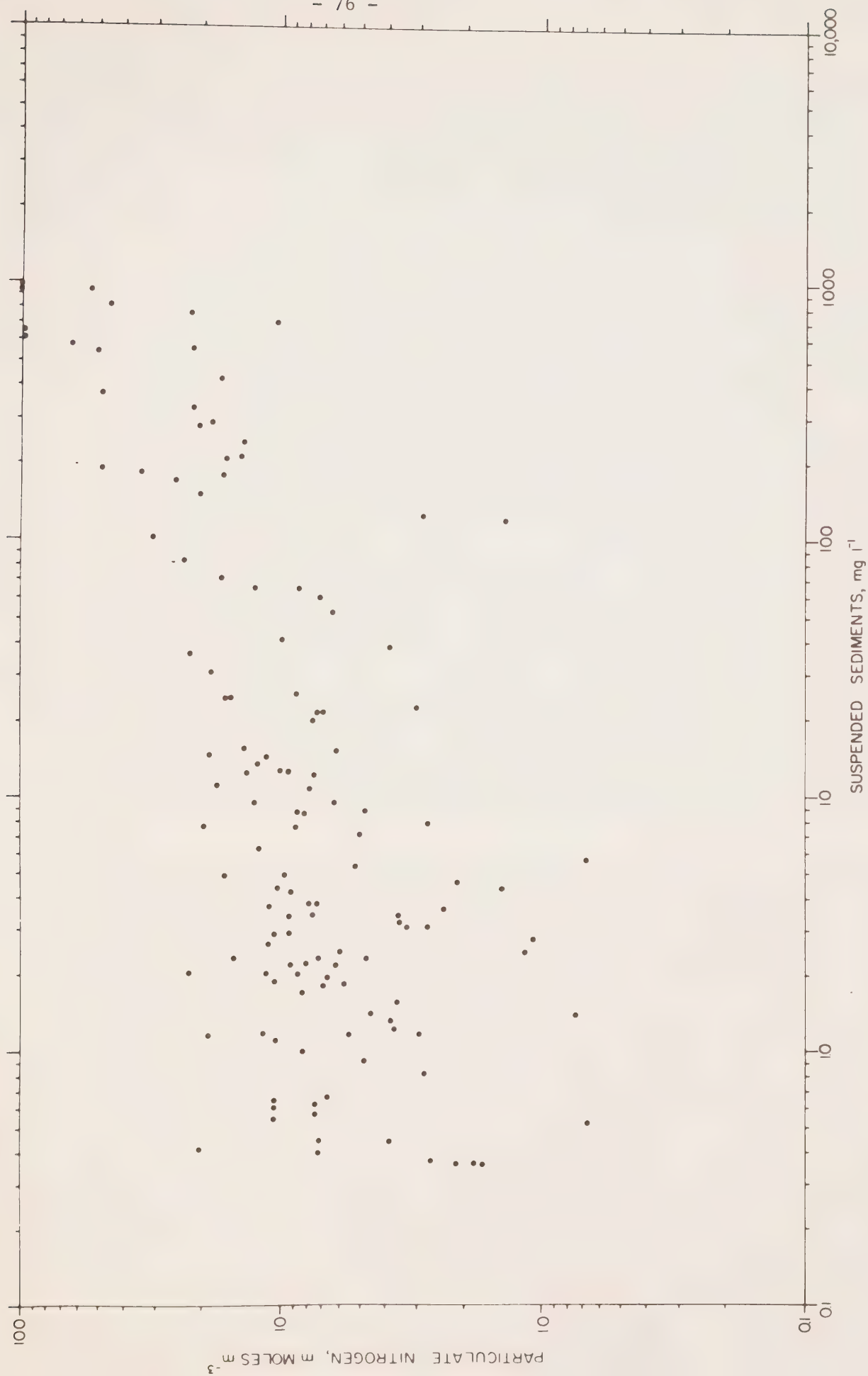


Figure 23: Relationship between concentrations of particulate nitrogen and total suspended sediment in N.W.T. and Y.T. rivers and streams during 1971-72.

sheets, carrying soil. The burnt area could be recognized only by the presence of a few burnt stumps, the rest of the slopes consisted of exposed earth and permafrost. It was obvious that the recent rains had eroded all the surficial material. Careless right of way clearance methods in pipeline construction could have similar results. The zoobenthic fauna was also considerably reduced, ranging from 18 to 57 organisms per square meter, as compared to 300 for rivers low in suspended sediments (Trail River, see Appendix III, Table 5, p. 10).

All of the Mackenzie and Peel River suspended sediment is destined for the Mackenzie Delta and the Beaufort Sea. We estimate (from Appendix X) that in 1971 about 160,000,000 metric tons of suspended sediment were water-transported to the Delta by the Mackenzie and Peel Rivers. This is an underestimate, since bedload and some large rivers were not sampled. This mass of sediment, distributed over the area of the Delta, gave an approximate sedimentation rate for the Delta of $13 \text{ kg m}^{-2} \text{ yr}^{-1}$. Much of this annual load is likely deposited in Mackenzie and Kugmallit Bays, and offshore from Richards Island in less than 3 months (June-August). It is likely that sedimentation rates for the clear, Southern Delta lakes are at least 1 order of magnitude less than this number, based on the duration of time that they are flooded by sediment-laden Mackenzie waters.

The sediment carried to the Beaufort Sea was largely illite, chlorite, and amorphous clay sized material. Trace amounts of kaolinite and montmorillonite were found in a few suspended sediment samples from the Mackenzie watershed, but these clay minerals were not abundant in our samples. Dewis et al. (1972) and Naidu et al. (1971) found larger amounts of kaolinite in Mackenzie Delta and Beaufort Sea sediments. These clays will likely yield Ca^{++} and H^+ to seawater solution, and take up Mg, Na, and K at the reaction sites of the clay mineral (Powers, 1959). Pollutants sorbed to clays will react differently in seawater than in freshwater: some heavy metals may be released from the clay to the solution, and petroleum-coated sediments are likely to remain in suspension in seawater longer than in freshwater (due to the difference in density between fresh and seawater).

Based on our crude estimates of transport rates for dissolved nutrients, 0.026 moles TDP m^{-2} , 0.47 moles TDN m^{-2} , and 0.8 moles Si m^{-2} are provided to Mackenzie Delta ecosystem annually. Again, most of this annual supply of nutrients flows directly through the three main channels to the Beaufort Sea. Perhaps 10% or less reaches the clear, southern Delta Lakes. Even this fraction of the nutrient load (supplied in 2-4 weeks during flood season) is rather high for lakes of mean depths 1-3 m and surface area 0.5-20 ha (see Vollenweider, 1968). If particulate phosphorus and nitrogen were added to this dissolved nutrient load, the lakes would appear in the meso to eutrophic region of Vollenweider's (1968) graph. It is not known whether Vollenweider's relationships among mean depth, rate of supply of N and P, and trophic status of a lake are pertinent to Arctic lakes. Based on this crude estimate of rate of supply of nutrients to the Delta, the observed concentrations of nutrients in Delta lakes (Appendix IX, Table IVd), and the readily observable variation in turbidity in this area, we feel that biological production in the Delta is not limited by nutrients, but by turbidity due to suspended sediments and climatic factors. This may be true for the flowing streams and rivers in the Fort Simpson and Old Crow regions, but more data are necessary to make this judgement.

In the Mackenzie Delta, the channels represent the most impoverished habitat since they combine two factors which are adverse to zoobenthos in this habitat: large amounts of silt and high current speeds. The latter factor predominates in midchannel and is the main reason for the lowest zoobenthos abundance in this region. Lower velocity regions of the channels, e.g. deposition banks, provide rich substrates for zoobenthic colonization where current speeds decrease sufficiently. The extreme margins of channels, especially in depositional zones yield the highest densities of zoobenthos in the flowing water of this region, although these are low compared to the standing crops of rivers in temperate areas (Albrecht, 1961).

The standing-water habitats of the Delta (lakes) provide "oases" for zoobenthic organisms. The clearer lakes especially have high production in terms of macrophytes which is reflected in the abundance and diversity of the zoobenthos. The main factors affecting this productivity are transparency, rate of nutrient supply, shallow depth, and accessibility of the lake surface to wind.

The discharge from the Mackenzie has a profound effect on the adjacent sea-area. True brackish conditions are not really encountered until the area of the alluvial islands (Hooper, Pullen, Garry Islands). The shallow bays immediately adjacent to the Delta are extremely impoverished with respect to infauna. This is a result of the shallow water depth, susceptibility to ice scour, and freezing of surficial sediments during winter (Mackay 1963). Colonization of these areas during the summer appears to be brought about largely by mobile forms such as amphipods and cumaceans. The density of infaunal types such as sedentary polychaetes and bivalves does increase with increasing depth, salinity and northerly latitude. Faunal densities of 4000 organisms per square meter consist of primarily marine components. The influence of the Mackenzie is reflected in the occurrence of moderate and large numbers of estuarine forms such as a brackish water variety of the marine bivalve Portlandia arctica, the calanoid copepod Limnocalanus macrurus grimaldii which is characteristic of low salinity waters (Patalas, personal communication) and glacial relicts such as the amphipod Pontoporeia affinis and Mysis relicta. Most of the polychaetes are members of families which have many representatives in low salinity waters (e.g. Spionidae).

For the Porcupine drainage, in almost all cases we found that the standing crop of zoobenthos per unit area decreased from the type A stream (Alpine) to type C (floodplain rivers, see Results, 6.2.1.). These results do not necessarily indicate a greater productivity of headwater areas. Production per unit length of stream could be similar to or greater in lower sections than upper ones, as downstream widening of the channel results in a larger sediment surface area.

Some of the differences that we found were the disappearance or reduction in numbers of Plecoptera and Trichoptera in stream Types B and C. Since these two zones in the Northern Yukon are synonymous with zones of deposition, we deduce that silt may be the limiting factor. Results of a mud slide on Caribou Bar Creek, a small tributary of the Porcupine River, showed a similar effect on Plecoptera and Trichoptera.

The faunal assemblages throughout the Northern Yukon were similar at the ordinal level. The following variations were evident. Amphipods showed a very clustered distribution, being collected only at the headwaters of the Bluefish and Driftwood Rivers. When amphipods were collected, they occurred

in dense concentrations indicating a contagious distribution. Pelecypods and gastropods were seldom collected, and in each case they were in the vicinity of a lake effluent. It would appear that these were two lacustrine taxa and their occurrence in the lotic system was limited.

In comparing the north slope rivers and the two south slope ones, few differences were apparent. The numbers of benthic organisms in south slope rivers appeared greater, due primarily to greater numbers of Chironomidae. Another noticeable difference was the virtual absence of Trichoptera from the North Slope, with the exception of two samples from the outlet of Trout Lake. The absence of this taxon is an expected latitudinal effect. The presence of Trichoptera at the outlet of Trout Lake probably indicates a variation in micro-climate brought about by the warmer standing waters of the lake.

In view of the fact that, almost without exception, the rivers in the Northern Yukon are clear most of the year, and that silt appears to alter the faunal composition, the area as a whole should be considered very sensitive to pipeline construction. Extreme care should be exercised when considering any mode of construction which could increase erosion at any level.

In order to illustrate the possible effect of watershed disturbance on the silt load of a stream, the following hypothetical, extreme cases are presented. Assume that a pipeline-road corridor is laid across the watershed of the Willowlake River about 24 km. upstream from its mouth. Assume further that the right-of-way for the corridor is 100 m wide, and that the terrain is disturbed such that a 0.1×42 km strip of land melts to a depth of 1 m. Roughly 50% of this volume will be water, and the remaining 2×10^6 m³ of sand, silt, and clay will be water-transported through the Willowlake River system over several years' time. Assuming a density of 2.3 g/cc for dry soil material, this would result in an average suspended sediment concentration of 2000 gm⁻³ for 2 years of river flow in May through September (Water Survey of Canada, 1970). If this amount of sediment was supplied to the river over 5 open-water seasons, the average concentration of suspended sediments would be 800 gm⁻³. Willowlake River suspended sediment concentrations ranged from 1-20 gm⁻³ in Summer, Fall and Winter, and up to 100 gm⁻³ during Spring floods in 1971-73. The natural rate of transport of suspended sediments off the Willowlake watershed is around 1 metric ton km⁻² yr⁻¹, whereas in the hypothetical case above the average suspended sediment transport rate would be 222 mt km⁻² yr⁻¹ over 5 years' time (see Table VIIb, Appendix X). From our limited bank and soil samples of the Willowlake River watershed, over 60% of the soil is in the silt and clay particle size range, which would dramatically alter the present stream bottom (largely sand and gravel) if added during low velocity-low discharge periods of the year.

If the corridor crossed the Willowlake River about 4 km upstream from its mouth, a strip of land 0.1×5 km would be disturbed. Using the assumptions given above, the sediment eroded from this disturbance would increase the suspended sediment load in the river to 240 gm⁻³ over 2 seasons, or 96 gm⁻³ over 5 seasons. This would appear as an increase in the rate of transport of suspended sediments as about 27 mt km⁻² yr⁻¹.

These calculations oversimplify complex irregularities in hydrology, soil mechanics, permafrost distribution, and the hydraulics of sediment transport. However, they illustrate the relationship between the magnitude of land area

Table XX Annual rates of transport of suspended sediment, ROT (SS), per unit watershed area, from small watersheds in temperate North America. Q_a = annual discharge in 10^3 m^3 , A_d = drainage area in km^2 , ROT (SS) in metric tons $\text{km}^{-2} \text{ yr}^{-1}$.

Watershed	Q_a	A_d	ROT (SS)	Disturbance	Reference
Beaver Creek, Arizona	582	1.84	8.13	none	Brown et al, 1970
Broad Ford Run, Maryland		19.2	3.85	none	Wolman, 1971
Hubbard Brook N.H. (W6)	100	0.132	2.5	none	Bormann et al, 1969
Hubbard Brook N.H. (W2)		0.156	10	Deforestation	Likens et al, 1970
Gunpowder Falls Maryland		784	283	Agriculture	Wolman, 1971
City of Baltimore Maryland		0.00647	49060	Construction	Wolman, 1971
Little Falls Branch Maryland		10.6	813	Construction	Wolman, 1971
Stony Run Maryland		6.39	18.9	Urban homes	Wolman, 1971
Pond Branch Maryland	61.1	0.384	1.12	none	Cleaves et al, 1970
Pond Branch Maryland		0.012	51.0	Pipeline construction	Cleaves et al, 1970

disturbed and resulting siltation of the river. It would appear to us that the larger the land area disturbed, the greater an increase in suspended sediments in the river would be expected. Many more kilometers of Willowlake River and tributaries would be affected by an assumed right of way 24 km upstream than by a crossing near the mouth. Although we do not yet have adequate data, we feel that the smaller watersheds ($<25,000 \text{ km}^2$) will be more affected by terrain disturbances than would be larger river watersheds. This is primarily a function of discharge, i.e., the capacity of the stream or river to transport sediment added to its normal annual load by increased erosion on its watershed. These calculations on the effect of watershed disturbances on suspended sediment loads in streams and rivers are supported by research in temperate North America (Table XX), where land disturbance caused increases in rates of transport of suspended sediments by one to five orders of magnitude. Pipeline construction through Pond Branch, Maryland caused a fifty-fold increase in suspended sediment transport rate (Cleaves et al., 1970).

If adequate precipitation, evaporation, discharge, and watershed area data were known for tributaries of the Mackenzie that we have not sampled, we feel we could estimate annual suspended sediment transport rates for these rivers. For example, the watershed of the Blackwater River appears similar to Willowlake River (lakes in the headwaters, vegetation, relief, geology, proportions of dissolved ions). Knowing that the Willowlake River watershed yields about $1 \text{ mt of sediment km}^{-2} \text{ yr}^{-1}$, this partial erosion rate could estimate sediment movement (per unit watershed area) in the Blackwater River. Thus, predictions could be made about the maximum sediment load in the Blackwater River by computing the product of watershed area and $1 \text{ mt km}^{-2} \text{ yr}^{-1}$. If additional climatic and hydrologic parameters were known, estimations of suspended sediment concentrations during high and low flow periods could be made. However, it would be far better to actually measure the annual suspended sediment load and discharge. With discharge data alone, minimal sampling for suspended sediments would yield crude estimates of annual transport rates. Daily suspended sediment transport rates could be crudely predicted from discharge (Fig. 2 and Appendix X) if some background data are accumulated for representative watersheds. This approach requires that fairly detailed suspended sediment and discharge data be available for a select group of "calibration watersheds".

Results indicated that in most cases an increase in suspended sediments, whether measured as Secchi visibility or suspended sediment weight, reduced the zoobenthic standing crop. This approach, though adequate for gross generalizations, is much too simple and masks other important environmental factors. Note differences in slope of the regression equations ((1), (2), (3), and (4), see p. 60).

For clarification, sections of streams in the Yukon and lower Mackenzie were grouped into Clear Upper, Turbid Upper, Lower Clear, and Lower Turbid Sections. The means of Surber samples (number of organisms per square meter) obtained are presented below.

	<u>YUKON DRAINAGE</u>			<u>LOWER MACKENZIE</u>	
	Clear	Turbid		Clear	Turbid
Upper	1152	57	Upper	306	30
Lower	248	112	Lower	172	38

Now it becomes evident that the upper parts of streams generally had a higher standing crop per unit area than did the lower ones. Because of their normally clear water and clean rocky substrates, headwaters suffered a greater reduction in zoobenthic standing crop than did lower sections when suspended sediment was increased. Lower sections, even when clear, are areas of sediment deposition, and the faunal assemblages there are already adapted to certain levels of disturbances. As a result, the effect of increased suspended sediment on the lower section of a river will be less pronounced than in the upper section, though a large increase in suspended sediment will lower the standing crop in both sections.

In a naturally turbid area, such as Mackenzie Delta channels, the presence of such large amounts of suspended sediment was probably the major cause for the low density and diversity of zoobenthos. This effect may be modified by current speed variations.

In the water bodies which are not subjected to high sediment loads (lakes in the Delta, clear rivers in Upper Mackenzie) high densities of a diverse zoobenthic faunal assemblage occur. The Delta lakes may contain some silt-tolerant species, as they are subjected to periodic pulses of turbid water inundation. The net result of such an influx, however, is still reflected in a lowering of zoobenthos density.

The tentative, significant level of suspended sediment in aquatic ecosystems studied on the Mackenzie system was 10-15 mg/l. A similar relationship was seen in the Porcupine system data. A river or lake habitat having a concentration of suspended sediments lower than this usually was "productive" and one with a higher concentration of suspended sediment was usually "impoverished" in terms of zoobenthos per unit area. This "critical level" of suspended sediment requires further verification. This "critical concentration" (10-15 mg/l) of suspended sediment is a static parameter, and will be of limited use in the monitoring and enforcement of tolerable limits of environmental disturbance. Natural catastrophic events (fire, landslides, late summer floods) will occur for short periods of time (1 week to several years) which will increase suspended sediment loads above this value. One feasible way of quantitatively monitoring natural sediment loads, and increases in suspended sediment loads due to construction disturbance, would be to measure the rate of transport of suspended sediments. This would entail the installation of discharge and sediment stations on a variety of sensitive streams in a given climatic region. Regulatory agencies could then select limits (perhaps "not to exceed maximum recorded rates of transport per year or per season") on groups of streams and rivers of similar terrain and hydrology.

The low numbers of zoobenthos in the turbid section of Caribou Bar Creek below the mudslide probably resulted from increased silt in a usually clear stream. Whether this reduction was due to suspended sediments, sedimentation, or a combination of both is not known; both conditions were present. Tebo (1955) found a similar reduction in benthic organisms in a stream where increased siltation reduced standing crop by 75%. The shift in dominance in Figure 15 is due mainly to the disappearance of the Trichoptera and a reduction in the numbers of Ephemeroptera. Species composition changes are further complicated by the Oligochaetes, a silt-loving taxon, which appeared downstream from the mudslide. Similar results are discussed by Hynes (1963),

who found a shift of the normal fauna under silty conditions to one dominated by *Oligochaetes* and *Chironomus*. Two weeks after the mudslide there was an increase in total numbers in both the disturbed and undisturbed areas, due to the appearance of first and second instar Plecoptera and Chironomidae. All taxa were reduced in the turbid stream sections with the exception of the *Oligochaetes*.

The clearing of a right-of-way for the Mackenzie Highway through the Martin River watershed in July 1972 has not yet resulted in any significant change in suspended sediment concentrations or transport rates, nor have concentrations of dissolved elements changed beyond expected natural variations. One crossing by a Nodwell vehicle disturbed benthic organisms briefly, but the benthic community appears to have satisfactorily recovered. Repeated crossings are likely to have greater effects. More intense construction activity may occur in 1973, and we will continue to monitor the effect of this disturbance.

The analysis of a limited number of samples taken from above and below a road-culvert crossing of the Poplar River indicated that aquatic organisms were deleteriously affected by the crossing, primarily due to the disturbance of the river substrate and the acceleration of water velocity in the culverts.

The interaction between nutrient transport rates and biological productivity of rivers, streams, and lakes is not known in the Mackenzie and Porcupine River watersheds. Observations on the effect of sewage wastes on streams and lakes near settlements (Fort Good Hope, Inuvik, Old Crow, Yellowknife, Fort Simpson, Resolute Bay) indicated that in these localities eutrophication resulted in increased biological growth and greatly accelerated O_2 depletion under the long period of winter ice cover. Construction camps of 300 men along the corridor will produce approximately 9.7 k mole (300 kg) $P\ yr^{-1}$ and 171 k mole (2400 kg) $N\ yr^{-1}$, based on Vollenweider's (1968) and Brunskill's (1972) estimates of 32-65 moles $P\ capita^{-1}\ yr^{-1}$ and 570-715 moles $N\ ca^{-1}\ yr^{-1}$ from Temperate Europe and North America. Most small, shallow lakes typical of the Mackenzie Valley (mean depth 1-5 m, surface area 1-60 ha.) would likely respond quickly to such an increase in nutrient supply by producing algal blooms in the summer and by O_2 depletion under winter ice. Massive amounts of nutrient-rich liquid wastes, whether treated or not, will accumulate as ice during Winter and will be released to the aquatic ecosystem by Spring melting. If liquid wastes were added to relatively large rivers ($>0.5\ km^3$ annual discharge), for a short time (<2 years), little effect upon aquatic organisms would be expected (e.g., there is little indication in zoobenthos communities of the effect of the sewage outfall of Inuvik into the East Channel of the Mackenzie Delta). For example, the Willowlake River annually transports about 774 k moles of dissolved phosphorus, and the addition of 9.7 k moles (the expected contribution from 300 people's waste over a year's time) is not likely to greatly affect the aquatic ecosystem.

In smaller streams ($<0.5\ km^3$ annual discharge) and lakes (<50 ha. surface area, <5 m mean depth), the residence time of the sewage organic matter and nutrients will be longer and thus more likely to alter the aquatic ecosystem. The solid wastes from construction camps should be incinerated since their presence in small lakes and streams would have long term effects on aquatic ecosystems.

In addition, many chemical toilet disinfectants (e.g., Monochem) contain high

concentrations of toxic or deleterious heavy metals, such as Zn and Cu. The effect of large amounts of these disinfectants would be maximum on small lakes and streams and possibly less desirable than the raw sewage. This discussion does not pertain to pathogenic bacteria and human health problems.

Water supply to construction camps will have to be carefully considered, since many moderate to small rivers and streams in the Mackenzie have very low discharge in late summer, fall, and winter. During these periods, withdrawal of 60 m^3 of water per day (~ 50 gallons capita⁻¹ day⁻¹ for 300 men) could possibly affect small ($<1000 \text{ m}^3$ day⁻¹) streams by reducing water depth in riffle zones downstream from intake pipes. This would be likely only during winter in streams of the magnitude of Martin, Harris, Jean Marie, and Trail Rivers. In winter, overflow sometimes occurs on these rivers, resulting in unusual (2-4 m) thickness of ice and slush ice which diverts the water flow up onto the river banks. It would appear to us that, for water supply and liquid waste disposal, the camps should be near larger ($>0.5 \text{ km}^3$ yr⁻¹ discharge) rivers.

Comparative data on rates of transport of nutrients and major ions in solution are not common in the literature. The data given in Table XXI indicate that 1) Western tributary-watersheds of the Mackenzie River annually yielded, per unit area, more Ca, Mg, K, HCO_3 , SO_4 , TDP, TDN, and Si than did the Eastern tributary watersheds, and 2) Eastern watersheds yielded more Na and Cl per unit area than did Western watersheds. The work of Hitchon et al. (1969) indicated that the Mackenzie watershed receives much of its Cl from subsurface evaporite beds in the Slave River area, and noted evidence of solution collapse structures in this area. The greater transport rate of Na and Cl from eastern tributaries to the Mackenzie suggests a similar source. The explanation for the relatively high transport rates for the other major elements (Ca, Mg, K, HCO_3 , SO_4) in Table XXI requires further study, but is probably related to variations in geology, relief, vegetation, permafrost regime, precipitation and evaporation (Gibbs, 1972, 1967a, 1967b; Hitchon and Krouse, 1972; Reeder et al., 1972). Similarly, the differences in nutrient transport rates between these two areas are noteworthy and require more detailed and frequent sampling to explain these differences. However, our studies indicated that biological growth was greater and more diverse in the clear, eastern tributaries of the Mackenzie. This fact, perhaps coupled with differences in the productivity and/or stability of terrestrial vegetation, may act to retain nutrients in the watershed. It is likely that disturbance of eastern watersheds to the Mackenzie will result in increased rates of transport of most dissolved elements as well as suspended sediment and water. Deforestation caused a two to forty-fold increase in major and nutrient element transport rates in a New Hampshire watershed (Likens et al., 1969, 1972: see Table XXI). It seems also likely that disturbances in permafrost terrain will result in greater increases in rates of transport of dissolved and suspended elements than would a similar disturbance in the temperate zone (e.g. Hubbard Brook W2, see Table XXI). Restabilization of a watershed by natural or seeded vegetation will probably reduce dissolved and suspended element losses, but will require a much longer growing time in the Sub-Arctic and Arctic climate compared to attempts at restabilization in Temperate zones (Marks and Bormann, 1972). Atmospheric pollutants (e.g., H_2SO_4 from the desulfurization of natural gas and oil) will likely alter the proportions and rates of solution of some elements being transported from watersheds (Johnson et al., 1972). Our limited data on the chemistry of rain (not reported here) show few signs of industrial atmospheric pollutants, except in the vicinities of settlements.

Table XXI : Rates of transport of dissolved elements from Mackenzie watersheds, and some temperate and tropical watersheds. ROT is given in kmol km⁻² of watershed area yr⁻¹. TDP = total dissolved phosphorus, TDN = total dissolved nitrogen.

Watershed	Ca	Mg	Na	K	SO ₄	Reference
Western tributaries of the Mackenzie	164-282	52-156	13-42	4.7-9.2	55-208	This report
Eastern tributaries of the Mackenzie	42-94	24-32	17-155	2.1-2.3	13-21	This report
Hubbard Brook, N.H. (W6, undisturbed)	26	12	30	4.3	18	Likens et al, 1970
Hubbard Brook, N.H. (W2, deforested)	192	67	79	59	16	Likens et al, 1970
Pond Branch, Md.	6.4	6.5	13	4.3	3.5	Cleaves et al, 1970
River Lowther, No. England	96	59	175	15	109	White et al, 1971
Amazon River	142	36	117	22	28	Gibbs, 1972

To be continued on next page

Table XXI continued:

Rates of transport of dissolved elements from Mackenzie watersheds, and some temperate and tropical watersheds. ROT is given in km^{-2} of watershed area yr^{-1} . TDP = total dissolved phosphorus, TDN = total dissolved nitrogen,

Watershed	C1	HCO_3	TDP	TDN	Si	Reference
Western tributaries of the Mackenzie	6.3-17	498-770	0.31-0.66	2.1-4.8	9-19	This report
Eastern tributaries of the Mackenzie	14-78	123-124	0.036-0.34	0.80-1.1	1.1-30	This report
Hubbard Brook, N.H. (W6, undisturbed)	13	3.3		11 ⁺	61	Likens et al, 1970
Hubbard Brook, N.H. (W2, deforested)	30	1.7		748 ⁺	111	Likens et al, 1970
Pond Branch, Md.	11	24			27	Cleaves et al, 1970
River Lowther, No. England	118			7.9 [*]	48	White et al, 1971
Amazon River	98	323	0.37 [*]	2.7 [*]	164	Gibbs, 1972

* Reported as PO_4 or NO_3 , not TDP and TDN.

+ Reported as NO_3 -N and NH_4 -N, not TDN.

Under winter ice, throughout the Mackenzie and Porcupine watersheds, concentrations of suspended sediment and discharge fall to very low values. Oxygen concentrations are frequently very low under winter ice, and temperatures are close to 0°C. To add sediment (containing organic matter) to a stream or lake during this period will likely further reduce O₂ concentrations. Highest O₂ concentrations in small streams usually occur in late summer and fall, when suspended sediment movement is low. This is likely due to photosynthetic production of O₂ by stream algae and macrophytic plants, and smaller amounts of organic matter in the water (which requires O₂ for decomposition). To add watershed soils and bank sediments to small streams during this period would reduce O₂ concentrations by inhibiting photosynthetic growth of stream or lake plants, and O₂ uptake by soil organic matter. It was also noted that the addition of crude oil (a form of carbon-rich suspended sediment) to Lake 4 resulted in a decrease in O₂ concentration (Appendix IX, Fig. 3j).

Terrestrial soils and bank sediments added to a stream in summer, fall, or winter would be only slowly moved through the channel in low discharge, low velocity streams. This is the period of time (summer and fall) when most active biological growth occurs. During winter, rates of growth of benthic animals are slower, but these organisms are nevertheless active and growing in a much more severe environment (low O₂, low temperature). During spring flood, most of the added soils and bank sediment would be flushed through the channel to the Mackenzie. Soils and bank sediments added to the larger, high velocity rivers in summer and fall would likely to be transported to the Mackenzie with little difficulty, but sediment addition to these rivers in winter would likely remain in the vicinity of the disturbance until spring flood. Water velocities in the large tributaries to the Mackenzie were usually very low in winter.

Zoobenthic organisms collected under ice during the winter from flowing water in the Mackenzie Delta and rivers in the Fort Simpson area were not only present in relatively large numbers but showed no reduction in activity as compared with their behaviour during summer months. Chironomid larvae which had been frozen into the substrate of Caribou Bar Creek during the winter of 1971-72 were active after being slowly thawed out. It is known that these larvae undergo partial dehydration in the ice of Arctic ponds and in this condition can tolerate more than 90% of their remaining body water as ice (Scholander et al., 1953). A similar tolerance is exhibited by certain intertidal marine molluscs (Kanwisher, 1955, 1959), and terrestrial insects can withstand a limited amount of supercooling (Salt, 1961).

The presence of early instars of larval insects during winter, especially in the East Channel of the Mackenzie Delta, indicated that winter may be a period of growth for these individuals. Larval insects were observed to be very active at winter habitat temperatures (0°C). Their metabolic rates were certainly not reducing them to the level of dormancy. This means that such larvae were either actively feeding (organic material and prey organisms are not limiting at this time) or living off stored reserves. The length of time such larvae are exposed to this temperature (half the year) coupled with their observed activity and the availability of food makes the latter likelihood improbable. During this time phytoplankton and phytobenthos production may increase as a result of increased water transparency. The duration of this period will be affected by the decreasing daylight of the Arctic winter. Additional indirect evidence of a winter algal bloom under the ice is provided by the presence of Copepoda during November and December 1972. Numbers of these organisms decreased markedly with decreasing day length.

The Delta major channels are sufficiently deep that they do not freeze completely to the bottom nor do they suffer a severe oxygen depletion (Appendix IX). Their zoobenthos is, therefore, unlikely to be adapted to severe changes either during summer or winter. The indigenous organisms are undoubtedly able to tolerate large amounts of silt, but the effect of silt in their environment during winter, especially on the early instars, is not known. The effect of oxygen depletion at this time as a result of the introduction of large amounts of organic debris (such as may occur during highway or pipeline construction) is similarly unknown. It is, however, likely to have a more deleterious effect than the introduction of silt alone at this time.

The relatively high numbers of zoobenthic organisms in the East Channel during winter as compared to summer were probably the effect of late season oviposition. The spatial separation of the sexes of Pontoporeia affinis during fall and winter (pelagic males) is known to occur in more southerly latitude (Bousfield, 1958). This species in the Delta also appears to have a 12-18 month life-cycle.

In Delta lakes, especially the silty ones, chironomid larvae are dominant and overwinter under different conditions to those in the East Channel. Most of the lakes are shallow and although they do not freeze to the bottom, the oxygen concentrations of the remaining water were decreased substantially or completely. The zoobenthos were, therefore, more likely to be tolerant of such conditions than that of the channels. There was evidence in the clear lakes that mulluscs, especially bivalves, bury themselves deeper into the substrate to avoid adverse winter conditions.

At first glance the composition of aquatic insects in the northern Yukon, Mackenzie Delta, and Fort Simpson appeared very similar; however, the similarity was superficial. In terms of numbers of genera (Appendix V) the Fort Simpson area was by far the highest followed by the Yukon and the Delta. In terms of standing crop, once again Fort Simpson was highest (Appendix III), while the other areas appeared impoverished. Some of the impoverishment may be an artifact of the times of sampling, as the standing crops vary greatly in short periods of time because of complex life cycles of the organisms. Such seasonal variations were evident in the data presented for the Caribou Bar Creek mudslide and oil spill experiments.

The characteristic that the three areas had in common was the dominance of dipteran fauna. In the Fort Simpson region, the Diptera were less dominant than in other areas; and the Trichoptera, Plecoptera and Ephemeroptera were more numerous (Fig. 2A). The reduction in the above three groups in both the Delta and northern Yukon relative to the Fort Simpson region appeared to follow the description of Downes (1964). He described the Ephemeroptera as being primarily a temperate and tropical taxon, which was found only in low numbers in the low Arctic. The Plecoptera and Trichoptera, although described by Downes (1964) as cool temperate taxa, tend to decrease in numbers of species with increasing latitude, and this was evident from our data. Downes (1962) mentioned the absence of Tabanidae and Odonata from the Arctic. Our data indicated an absence of tabanids from both the Delta and northern Yukon. Five genera of Odonata were collected at Fort Simpson, three in the Delta and none so far in the Yukon, although they are known to be present. The nine species of Simuliidae which Downes (1962) described as truly arctic have not yet been found in our samples. From the data discussed

above it appeared that although the Mackenzie Delta and especially the Northern Yukon displayed some characteristics of high Arctic biological associations, their taxa were too diverse to be classified as high Arctic. These two areas appeared to be intermediate between Arctic and Temperate faunas, while the Fort Simpson area was characterized by a cool temperate fauna.

The family Chironomidae also showed interesting trends. Oliver (1968) stated that Chironomidae in the Arctic constitute one-fifth to one-half of the total number of Arctic insects. Since presumably he included terrestrial insects as well as aquatic, the above generalization cannot be accepted totally in our discussion. In our study areas, the Chironomidae made up 47% of the genera of aquatic insects found in the Northern Yukon, nearly 58% of the genera in the Delta and only 27% of the genera in the Fort Simpson region.

The generic composition of the Chironomidae of the three areas (Fig. 2 B) showed marked differences. The Northern Yukon was dominated by the Orthocladiinae, the other groups being markedly reduced. Chironomiinae were present in substantial numbers of genera, but were less abundant (in numbers of genera) than in the Delta and Fort Simpson regions. The Diamesinae, although lowest in percentage genera composition, were represented by five genera, as compared to two in the Delta and one in the Fort Simpson region. Oliver (1971) indicated that the Diamesinae are a cold-adapted group inhabiting circumpolar regions and mountain ranges. The Orthocladiinae, the dominant group in the Yukon, are widespread but are also the dominant subfamily in the Arctic (Oliver, 1968), and its dominance decreases as latitude decreases.

The Mackenzie Delta demonstrated a reversal in composition (Fig. 2 B) compared to the Northern Yukon, with the Chironomiinae being dominant. The other Chironomidae families had similar distributions, with the exception of the Diamesinae which were very low in numbers of genera. The Chironomiinae as a subfamily was widespread in occurrence, decreasing in numbers with latitude, or its climatological equivalent (Oliver, 1971). As a subfamily they tend to inhabit rich, warm, standing waters, though they are also found, in reduced numbers, in cool running waters.

The distribution of the Chironomidae in the Fort Simpson region was closest to that expected in a temperate zone. All of the subfamilies were well represented with the exception of the Diamesinae. There was no dominant subfamily as in the other two areas. The Chironominae and the Orthocladiinae had the greatest abundance, but the Tanypodinae occurred nearly as frequently.

The above discussion of aquatic insect distributions can be summarized as follows:

1. The three areas differed in their aquatic insect fauna, both in terms of taxa present and numbers present; the Northern Yukon appeared more closely related to the Arctic insect fauna, although it had a higher diversity and had taxa present which are traditionally absent from high Arctic assemblages;
2. The Mackenzie Delta aquatic insect fauna, although impoverished in numbers of genera, had strong similarities to some temperate aquatic insect assemblages. The dominance of the Chironominae, and the taxon diversity of the Oligochaeta (Appendix V) are compatible with our chemical data indicating that the Delta receives large amounts of sediment and organic matter. Hynes (1952) referred to areas which were disturbed by silt and organic matter enrichment, which become dominated by Chironomidae and Oligochaeta. Of the

three areas studied, the freshwater portion of the channels of the Mackenzie Delta had the lowest diversity of genera. The Fort Simpson area was by far the richest in the abundance of invertebrate organisms and numbers of taxa. Diversity of genera was high, and the biological assemblage was characteristic of the cool-temperate zone.

A consideration of the Mollusca and Oligochaeta taxa, which are present in aquatic habitats at all stages of their life-cycle, enables some zoogeographic generalizations to be made because dispersal by these two taxa would be via extant or once existing water courses. Mollusca are interesting because of the total absence of species found exclusively in the Northern Yukon. It appears that the molluscan fauna had to enter the Northern Yukon from the Mackenzie Basin. About 19% of mollusc species were present in all three localities (Fort Simpson, Mackenzie Delta, Northern Yukon). The zoogeographic link between the Delta and the Fort Simpson region appears to be strong, since about 30% of the species were present in both areas. The high number of mollusc species found in the Delta may be a reflection of the variety of ecological niches available to molluscs, rather than a zoogeographic phenomenon.

The Oligochaete fauna presented a totally different picture. Numbers of organisms characteristic of each of the three areas were collected. There appeared to be little affinity between Fort Simpson and Delta oligochaetes, or between Fort Simpson and Northern Yukon oligochaetes. There was a closer affinity between the Northern Yukon and the Delta than any other combination. The evidence seems to point to an exchange of taxa between the Yukon basin and the Mackenzie Delta (probably after the last glaciation). It seems unusual that so few of the Fort Simpson oligochaete species (which make up 45.16% of total taxa) have managed to disperse to the Mackenzie Delta. It could be that post-glacial recolonization of oligochaetes from the South has just reached the southern fringes of the Mackenzie River.

The seemingly paradoxical results of the Oligochaeta-Mollusca post-glacial dispersion can be better understood when their modes of reproduction are considered. Of the Mollusca, the Gastropoda (apart from viviparous species) place their eggs in gelatinous cases attached to the bottom, to floating debris, and on rooted aquatic vegetation. In addition, most adults survive certain degrees of desiccation, and often spend some time attached to floating debris. Of the Pelecypoda, the Unionidae disperse by means of glochidia attached to fish. With the proper host fish available, distribution through a river system would be quite rapid.

The oligochaetes do not have any of the above dispersal adaptations. Being primarily sedentary at every stage of their life cycle, they have a much slower dispersal rate. This could account for the slow dispersal of oligochaete species from the Fort Simpson region, compared to mollusc distribution. Post-glacial movements between the Yukon and the Delta could take place through the Upper Bell-Summit Lake-Rat River route where the two drainages are joined during spring; or through the upper Eagle River watershed.

7.2. The Effects of Oil on Aquatic Ecosystems

The immediate effect of crude oil on the Caribou Bar Creek ecosystem was unquestionably detrimental. On contact with oil, zoobenthic organisms

exhibited an avoidance reaction, leaving the oiled section of the stream in large numbers by entering the drift. This is recorded in Figs. 4 a and b by peaks shown by all taxa between 1400 and 1600 hours. The disparity in amplitude between Figs. 4a and b is due to a leak in one drift net. The secondary peaks in all taxa during the first 12 hours were likely due to the toxic effect of the oil.

As indicated in the results, the magnitude of the drift during the oil spill experiment increased nearly 12 times the value of the previous week. When the data are treated as taxon percent composition of the total drift, the greatest deviations from the control drift station were found in Plecoptera and Ephemeroptera. In the control drift data the contribution of these two taxa to the total increased approximately 1.5 times and 1.25 times, while at the experimental oil spill station the increase was approximately 4 times. In terms of actual numbers of organisms, the Ephemeroptera had 14 individuals drifting in the control stream on 12 August 1972, and 14 on 17 August 1972. In the experimental creek 19 drifted on 12 August 1972 (before the oil spill) and 420 five days later, after the oil spill. The Trichoptera showed a similar behaviour, actually decreasing in the control stream from 28 to 18, but increasing in the experimental oil spill area from 20 to 508. Such results emphasize the sensitivity of these two taxa to Norman Wells crude oil in water.

If one assumes that the drift density was uniform through the cross sectional area of the stream, then we can estimate the number of organisms which have left the experimental area after the oil spill. From Table IX we have 4140 organisms drifting through 300 cm^2 of water per 24 hour period. During the 24 hours the cross sectional area increased from 1.39 m^2 to 1.98 m^2 ; the mean of the two was used (1.68 m^2). The estimated drift after the oil spill was 231,840 organisms. Assuming that the 50% reduction in drift between the two dates in the control station to be a widespread seasonal effect, the expected drift in the experimental creek would be 346 per drift net or 19373 organisms total. Subtracting the expected number of drifting organisms (19373) from the observed number (231,840), we have a loss of 212,467 organisms from the experimental area. This value represents 1) benthic animals which would normally have settled to the bottom (but did not because oil had made the substrate unsuitable), and 2) resident organisms leaving the experimental area.

From the Surber Sampler data tabulated in Table X we find that both in control and experimental stations the zoobenthos decreased in numbers. Several control stations showed the same reduction as station 1. From a series of transit and tape measurements on the experimental stretch we were able to estimate the substrate surface area to be 1605 m^2 . Using the density of invertebrates obtained at station 1 we estimated that there must have been 589,182 organisms present in the experimental area prior to the oil spill. Using the values obtained from station 3, on August 17, (Table X) we estimated the actual standing crop at 386,901 organisms. The difference between the expected and observed (202,280) should represent the number of organisms leaving the experimental area as a result of the presence of oil. This value compares favourably with the numbers of organisms observed drifting out of the systems (212,467).

Therefore it was concluded that the addition of 250 l. of Norman Wells crude

oil on a section of a low arctic stream removed more than 33% of its zoobenthic standing crop. Oil spills of a greater magnitude would be expected to have more disastrous effects.

Samples collected two weeks later indicated great increases in total numbers of all stations. This increase was due mainly to the appearance of first instar larvae of aquatic insects. At this late date the experimental area still exhibited a 20% reduction in standing crop. This area did, however, show signs of having been recolonized. It is difficult to speculate on the effects of oil on overwintering organisms, as we have no winter data to date.

Examination of phytobenthos samples indicated no change in composition before or after the spill in either control or experimental sections. Visually, there seemed to be a denser growth in the spill than in the control area; however, our methods were not refined enough to detect this with certainty.

The effects of oil in a lacustrine ecosystem were different from the flowing water system reported above. These differences reflect the differences between these two radically dissimilar habitats although zoobenthic organisms were still adversely affected.

Limited samplings of the microbial population of Lake 4 and its control lake (LC4) do not allow any clear patterns to emerge. However, the relatively large increase in counts of the microbial population in the water of Lake 4 (L4) between September and November was not seen in the data for LC4. This increase in bacterial biomass may have been a result of bacterial utilization of the crude oil spilled on L4 on September 5. Increased heterotrophic activity and growth was reflected in a decrease in oxygen concentrations (see Appendix IX, Fig. 3j and Fig. 3k). Alternatively, the higher bacterial count from L4 in November may represent a dispersion of the epiphytic flora of the large population of macrophytes which exists in the lake, in contrast to LC4. Of 252 isolates taken from the two lakes to date, 40 demonstrated some degree of oil degradation, and 12 of these formed very turbid suspensions accompanied by the visual disappearance of the added oil. These cultures are being stored for future study.

Although no primary productivity data are available yet, a reduction in this parameter is expected to occur as a result of the oil spill. Dickman (1971) found that oil added to water samples from the vicinity of Inuvik decreased C-14 uptake by photosynthetic organisms by 90%. A 50% decrease in photosynthetic uptake of C-14 in an Alaskan tundra pond has also been reported (Alexander et al., 1972).

The profundal benthos of Lake 4 showed no immediate effects of the oil primarily because the bulk of the oil was concentrated around the lake margin shortly following the spill. Longer term effects may become apparent when the oil at present in a littoral position has a chance to mix throughout the whole lake. This is most likely to occur during the spring of 1973. Oil pollution has been shown to produce a general impoverishment of lake profundal benthos and subsequent failure to recolonize oiled sediments after oxygen depletion (Bengtsson and Berggren, 1972).

The littoral benthos of most lakes is usually far more diverse than profundal

benthos. This was true of Lake 4 although there were only twice as many taxa represented in the littoral zone as in the profundal. This is the result of the small area of the lake and its shallow depth (see Appendix XIII)

A consideration of the genera of chironomid larvae present in the oil-rich surface film revealed that six genera were common to both littoral and profundal zones, five were common only to the littoral, and none were common only to the profundal. It would therefore seem that the majority of genera collected in the oil film after the spill had come from the littoral zone.

The gerrids (water-striders of the species Macrovelia buenoi and Gerris buenoi) were immediately incapacitated by the oil as a result of the lowering of surface tension of the lake. These species and several beetles have not yet recolonized the lake. Beetles were also affected deleteriously very soon after the spill. They were probably unable to replenish their air supply at the water surface as a result of respiratory organ clogging by the crude oil. Any organism associated in any way with the surface-film was likely to be immediately and irreversibly affected by spilled crude oil.

The huge increase in numbers of invertebrates in the oil film is probably the result of an aggregation of plant debris as the oil slick moved across the lake surface and around its margins. The decrease in numbers of littoral benthos during the same time may well be the result of an increase in vertical or horizontal migratory activity, causing them to become trapped in the surface oil-film or to move into other areas of the lake. Further studies of recolonization patterns during the next year should elucidate the longer term effects of the oil on zoobenthos and on macrophytic vegetation as well.

It is difficult to separate the effects of the oil spilled in Yellowknife Bay from the effects of the city of Yellowknife, especially at the 0.5 m disturbed section. The standing crop in the oil-polluted bay was nearly twice that in the control, but the taxonomic composition was very different (Table XII; Fig. 1 and 2, App. XII). We do not believe that the period between the spill's occurrence and the sampling date is long enough for recolonization by such members of new taxa to occur in the disturbed area. Therefore it would appear that, at the 0.5 m station, the effects of oil on aquatic organisms were masked by an accumulation of industrial and domestic wastes. The situation showing the greatest effect of the oil was at 2.0 m, located a few meters from the oil source. Here the amphipods were reduced to 1/20th the control densities. Due to their high mobility they probably left the disturbed area. All other taxa, except the Oligochaeta, were reduced or absent. At the 4.75 m station all taxa were reduced, though it was difficult to separate the influence of the spilled oil from industrial and domestic wastes. As in other silt and oil experiments in this report, we found that the Trichoptera were adversely affected by both oil and human wastes. Because of their apparent sensitivity, the tolerance levels of the species involved should be studied in more detail.

Oil-dipped and non-dipped artificial substrates in the Liard River in the August to September sampling period both showed low diversity because of the high percent occurrence of Simuliidae. The same was true for the Mackenzie River East Channel substrates, but in this case with respect to

Trichoptera. However, in the August to October set of artificial substrates from the Liard River, diversity of non-dipped substrates was higher than for the oil-dipped ones. The same was true for both sets of artificial substrates from the Trail River. The Caribou Bar Creek results, however, indicated a more equitable diversity for both sets of artificial substrates.

In the Trail River, four genera of Trichoptera were absent from Station 1 (control) and 2a (oil-dipped) while only two are absent from Station 2 (control) (see Tables XVI to XIX). It would appear the Athripsodes was more abundant at Station 2a but Oecetis was not as abundant at 2a as the two control stations. Thus, there was no clear preference among the Trichoptera for oiled or non-oiled substrates. Of the seven genera of Ephemeroptera reported only one was absent from Station 1 and two were absent from Station 2. However, four genera were absent from the oil-dipped substrate (2a). The genera Baetis and Ephemerella very definitely favored the oiled substrates while the reverse was true of Heptagenia and Stenonema. The other genera did not show clear trends. Only two genera of Simuliidae were found. Prosimulium was present only on the oil-dipped substrates (albeit only two specimens) while Simulium favored the oil-dipped substrates. The Chironomidae, the most diverse group to be examined, also showed marked differences in distribution between oil-dipped and non-dipped substrates. The genera were absent at each of Stations 1 and 2 but six were absent from Station 2A. The genera Cricotopus, Eukiefferiella, Microcricotopus, and especially Orthocladus or Cricotopus were present in greater numbers on the oil-dipped substrates than the non-dipped ones. On the other hand, individuals of Corynoneura, Nolotanypus, Polypedilum, Rheotanytarsus, Synorthocladus, and Thienemanniella were present in greater numbers on the non-dipped substrates. The other genera either did not show a preference or displayed no clear trends. Thus, in all but the Trichoptera, further qualitative and quantitative differences in fauna have been shown to exist between oil-dipped and non-dipped substrates.

In the East Channel, fewer Trichoptera were found in the oil-dipped substrates than in the non-dipped ones, but the ratio of the occurrence of the two genera (Neureclipsis and Hydropsyche) was the same on both. Neither of these two genera occurred in the Trail River. Of the Ephemeroptera, Baetis occurred only on oil-dipped substrates but Ephemerella occurred on both oil-dipped and non-dipped substrates. In the Trail River, both of these genera showed a preference for oil-dipped substrates. The occurrence of Simuliidae in the Liard River and East Channel is problematic as these organisms are usually rigidly restricted to fast-current areas (Harrod, 1964) with little or no suspended sediment. They will, however, exist in turbid conditions when current speed is great enough to prevent accumulation of silt on surfaces favorable to colonization by these larvae (Wu, 1931). This is probably the reason for their occurrence in the Liard River and East Channel of the Delta. More Simuliidae were found in the non-dipped substrates than in the oil-dipped ones in the July to August and the August to September sets in the East Channel and the Liard respectively. A later set of artificial substrates from the Liard River, however, showed the opposite effect.

In comparing the percent occurrences of taxa on oil-dipped and non-dipped substrates for all the rivers of the study during the open-water period, the Chironomidae were the only taxon to show a definite trend. They appeared to prefer oil-dipped substrates. Within small rivers, the Plecoptera preferred non-dipped substrates (as did the Chironomidae) and within the

large rivers, the Oligochaeta preferred the oil-dipped substrates.

In summary, Chironomidae dominated the fauna of the two small rivers of the study, the Trail and Caribou Bar Creek. Simuliidae and Trichoptera dominated the fauna of the Liard and the Mackenzie East Channel respectively, the two large rivers of the study. Over twice the total numbers and mean number of organisms per substrate characterized the non-dipped substrates, as compared to the oil-dipped ones in the two large rivers. The reverse was true of the Trail River. Caribou Bar Creek showed virtually no difference between oil-dipped and non-dipped substrates.

It is unlikely that we are ever going to know all the physical and chemical parameters that control the growth and reproduction of aquatic organisms. Therefore, we have good reason to suggest that at least the obvious parameters of importance to the health of aquatic ecosystems (rates of transport of suspended and dissolved elements, temperature, oxygen, bottom sediment size and composition) should not be altered beyond their natural ranges of variation. This advice would be sound if we had in hand adequate data over a significant length of time (~5 years). The data presented here (1971-72) represent a useful beginning toward this objective.

8. CONCLUSIONS

- 1) In the Mackenzie-Porcupine watersheds, aquatic habitats that had large concentrations and transport rates of suspended sediment had small standing crops of zoobenthos, compared to aquatic habitats that had low concentrations or transport rates of suspended sediments. This conclusion was reinforced by observations of the reduction of zoobenthos abundance in clear streams when subjected to increased suspended sediment.
- 2) A tentative "critical level" of 15 mg. suspended sediment per liter was deduced from observations of the occurrence of zoobenthic organisms in turbid and clear waters of the Mackenzie watershed. In aquatic habitats with greater than 15 mg. suspended sediments per liter, fewer and less diverse benthic organisms were found, compared to clear water habitats.
- 3) An increase in suspended sediments in a normally clear lake or stream of the Mackenzie-Porcupine watersheds resulted in changes in the taxonomic composition of zoobenthos. The duration of the change and rate of recovery of the habitat is currently being investigated.
- 4) Headwater sections of rivers and streams had higher zoobenthic standing crops per unit area than did lower reaches of rivers and streams. Headwaters acted as a zoobenthos reservoir for colonizing downstream disturbed areas.
- 5) The large, western tributaries of the Mackenzie River transported large amounts of suspended sediment in a relatively short open-water season. These sediment transport rates (per unit area and time) were large even when compared to temperate and tropical rivers which have technologically disturbed watersheds, and were at least an order of magnitude higher than the data available for Subarctic and Arctic rivers of the U.S.S.R. These western tributaries are characterized by greater velocity and discharge compared to eastern tributaries of the Mackenzie.
- 6) The smaller eastern tributaries of the Mackenzie are relatively clear and transport very small amounts of suspended sediment. These rivers are also characterized by lower water velocity and discharge compared to the western tributaries.
- 7) An increase in the concentration or rate of transport of suspended sediments usually resulted in an increase in concentration or rate of transport of particulate nutrient elements (carbon, nitrogen, phosphorus), but did not increase dissolved nutrient concentrations.
- 8) In rivers with high concentrations of suspended sediment ($>200 \text{ g m}^{-3}$), a greater proportion of the suspended material was inorganic matter; whereas in rivers with low concentrations of suspended sediments, a greater proportion of the suspended material was organic matter.
- 9) Rates of transport of dissolved elements (Ca, Mg, K, SO_4 , HCO_3), normalized to unit watershed area and time, were considerably higher for western tributaries of the Mackenzie compared to eastern tributaries. Per unit

watershed area, the eastern tributaries of the Mackenzie yielded more Na and Cl than did the western tributaries.

10) Rates of transport of dissolved nutrient elements (total dissolved phosphorus, nitrogen and silica), per unit watershed area and time, were usually higher for western tributaries of the Mackenzie than for eastern tributaries, but there were exceptions to this generalization. Transport of particulate nutrients (per unit watershed area) was much greater for western tributaries to the Mackenzie than for eastern tributaries.

11) The generally high rate of transport of dissolved and particulate nutrients in the western tributaries of the Mackenzie are probably of small importance to aquatic biological communities, due to the limitation of biological growth by extreme turbidity (reduced light penetration for algae growth) and abrasion. The generally lower rate of transport of nutrients in the clearer waters of the eastern tributaries to the Mackenzie are probably more important to aquatic biological communities, since these systems are less controlled by the effects of suspended sediment.

12) In many rivers and streams during peak flows of turbid water in spring and summer, O_2 concentrations were often less than 60% saturation. With reduced discharge and suspended sediment loads, O_2 concentrations approached saturation in fall.

13) Lakes and streams with small watersheds ($>5000 \text{ km}^2$) are likely to be affected by terrain disturbance to a greater extent than larger watersheds. The magnitude of physical, chemical and biological consequences of increased rates of supply of watershed soils and plant material to aquatic ecosystems is likely to be more deleterious in smaller watersheds compared to larger watersheds. The ecosystem changes resulting from a disturbance on a small watershed are more likely to be of an irreversible nature, whereas similar disturbances on large watersheds will likely be of short duration in their impact upon aquatic ecosystems.

14) Rivers and streams with high water velocities ($>1 \text{ m sec}^{-1}$, e.g. most sections of the Liard, Redstone, Keele, Mountain, Peel and Mackenzie Rivers, and Mackenzie Delta Main Channels) carried large amounts of suspended sediment, and yet maintained relatively clean bottom substrates suitable for zoobenthic colonization and growth. Rivers and streams with lower water velocities ($<0.5 \text{ m sec}^{-1}$, e.g. Horn, Rabbitskin, Jean Marie, Martin, Trail, Hare Indian Rivers) carried less suspended sediment, and when subjected to increased rates of supply of sediment, could not transport this sediment. This resulted in the deposition of fine silts and clays on gravel and boulder bottom substrates, and was apparently deleterious to the growth and reproduction of zoo- and phyto- benthos.

15) The channels and lakes of the Mackenzie Delta were well supplied with nutrient elements P, N, and Si. The aquatic production of this region appeared to be controlled by turbidity, substrate stability, abrasion and climate, rather than by nutrients.

16) From our limited data, it would appear that more elements are transported in the suspended, particulate phase, than in solution.

17) Rates of transport of suspended and dissolved elements to southern Mackenzie Delta lakes were very great in late May and June, and decreased greatly throughout the rest of the year. During July - winter, these lakes were of clear waters, fairly rich in nutrients, and supported large growth of aquatic macrophytes and zoobenthos.

18) Under winter ice cover, suspended sediment transport rates, velocity and discharge decreased dramatically. Oxygen concentrations decreased to less than 50% saturation in some small streams, which was probably due to the natural transport of dissolved and particulate organic matter under winter ice.

19) During winter, the zoobenthos of large bodies of water flowing under ice (which are not subjected to significant depletion of oxygen) show no marked differences from fall abundance and diversity. Furthermore, the activity of these organisms does not appear to be significantly depressed by low temperature conditions. This is particularly true of the Mackenzie Delta channels.

20) The magnitude and diversity of zoobenthic drift in clear rivers studied were reduced under winter ice. This did not occur in larger turbid rivers, e.g. the Mackenzie in the Delta, which present a completely different aspect during winter than at any other time of the year. In this case, suspended sediment levels are extremely low, resulting in increased transparency. This appeared to allow algal growth under ice until limited by winter light conditions. This algal growth resulted in an increase in the numbers of planktonic copepods present in the water column during the early part of winter, together with small, but measurable numbers of drifting zoobenthic invertebrates.

21) Examination of drifting invertebrate organisms above and below a culverted road crossing of the Poplar River indicated a lower diversity of organisms below the road crossing.

22) Studies of drifting invertebrate organisms in the Martin River indicated that crossings of the river by a Nodwell vehicle caused disturbances to the stream sediments. This sediment disturbance resulted in increased numbers of benthic invertebrates moving downstream from the disturbance.

23) The aquatic ecological impact of the Mackenzie Highway crossing of the Martin River has been small to date.

24) Approximately 225 liters Norman Wells crude oil, when released over a five minute period into a turbulent creek having at the time of release a discharge of $0.45 \text{ m}^3 \text{ sec}^{-1}$, produced a coating of oil which remained in the sediment for at least two weeks. This occurred even after a period of high water.

This amount of oil became well mixed in the turbulent stream. The initial oil slick did not remain at the surface as a slick, and could not be recovered by a boom.

The immediate biological effect of this spill was a tremendous increase in zoobenthic drift with disruption of the normal drift patterns. The duration and significance of this disturbance are now being studied.

25) Norman Wells crude oil (400 l.) when spilt onto a small (0.65 ha.) productive Mackenzie Delta lake, was seen to accumulate almost exclusively around the lake margin, especially on and among the emergent macrophyte communities. This occurred within a matter of hours of the spill. There was no evidence of natural oil breakdown two months after the spill.

The immediate biological effect was a mass mortality of zoobenthic invertebrates. The most pronounced effect was upon littoral organisms, especially those dependent upon the air/water interface. The deeper living zoobenthos appeared to show no immediate adverse effects. The duration and significance of this disturbance are now being studied.

26) Certain taxa appeared to be more susceptible to disturbance by oil or increases in suspended sediment. Such taxa are useful as "indicators" of disturbances of this kind. They include trichopteran larvae, certain species of mollusc, ostracod and chironomid larvae.

27) The presence of Norman Wells crude oil on artificial substrates in rivers affected their colonization by zoobenthic organisms. Changes occurred in the abundance and diversity of colonizing organisms when compared to control substrates. In some cases, reductions of as much as 50% colonizing individuals occurred on oil treated artificial substrates suspended in large turbid rivers, whereas the reverse appeared to be true in smaller, clear streams.

9. RECOMMENDATIONS and IMPLICATIONS

9(a) Matters of general scientific importance.

1) The ease with which the faunal composition and density of Arctic aquatic systems, especially the smaller ones, were changed by minor disturbances, indicated that their stability can be readily upset. The degree of irreversibility of stability breakdown was dependent upon the nature and magnitude of the disturbance and also upon the type of habitat.

The time of recovery of such systems will likely be lengthened, compared to temperate regions, by the unique climate and hydrology of Arctic and Subarctic areas.

2) The standing crop of zoobenthos decreased moving from southerly temperate latitudes to those of the Arctic North. Mean zoobenthos densities in upper Mackenzie areas ranged from 5,000 - 50,000 individuals/m² as compared to 100 - 400 individuals/m² in lower Mackenzie areas (Delta channels). Zoobenthos density in the Yukon and North Slope areas ranged from a few hundred to a few thousand organisms/m². In these latter sparsely populated northern systems, a breakdown in food-webs will have serious, far reaching, deleterious effects.

3) The rapid responses of certain groups of zoobenthic organisms to increased rate of supply of sediments and the presence of oil suggested the possibility of their use as indicator species. Their biology and ecology requires more study, with respect to this possibility.

4) The mechanism of ecosystem response to pipeline disturbance is a prime consideration. Changes of zoobenthos abundance and diversity in this respect is especially important as a result of the fundamental role of benthic organisms in aquatic ecosystems. Patterns of species replacement and their relationship to those exhibited by other aquatic ecosystems together with a knowledge of the time and nature of recovery processes is of great importance.

9(b) Matters related to pipeline and highway construction and maintenance.

1) In view of the results related to silt in aquatic systems so far obtained, and because of the role in the food web played by the zoobenthos, we recommend that whenever possible, the crossing of small, clear streams be avoided. If this is impossible, extreme care must be exercised in crossing these streams so as to increase the silt load for as short a time as possible.

Crossing of streams near their mouths should be encouraged, as the damage to zoobenthos should then be minimized. It appears that the larger, faster, and muddier a stream is, the less likely it will be to suffer from the effects of siltation.

In highway construction, bridges should be used for all crossings of

ivers and streams of watershed area greater than 500 km². In our opinion, based largely upon observations of Mackenzie and Dempster Highway construction techniques, culverts have a far greater deleterious effect on aquatic systems than do bridges. Culverts which constrict the natural river bed flow during any part of the season will have deleterious effects upon the stream biota.

2) In selecting the crossing site, care must be taken in choosing areas where the terrain is such that the cut and fill materials will stabilize quickly and not undergo solifluction and erosion during the summer. In this respect, terrain stability expertise should take priority over fishery and aquatic biological considerations.

3) Crossing of streams should be confined to winter periods when discharge is minimal or nonexistent. Under these conditions, the silt will be deposited over a minimal area, and will be carried out during the spring high water. The system should thus be left virtually unchanged if recommendations 1 and 2 are also followed.

4) Current speed is an additional factor to be considered when additions of silt to a stream ecosystem occur. There should be sufficient current to maintain the silt in suspension. Pools and still areas in the stream will act as settling zones for suspended material, and this may result in the elimination of nursery areas for fish-fry, by decreasing the zoobenthos and/or plankton abundance.

5) The critical level for suspended sediments in aquatic ecosystems of clear streams and lakes studied appears to be 10 - 15 mg/l suspended sediment. Care should be taken not to allow this level to be exceeded during pipeline construction in stream watersheds which normally carry less than this amount throughout most of the open-water season. In this respect, the most critical times will be during low flow conditions (i.e., July through September).

6) The following areas are to be regarded as ecologically sensitive to corridor development:

- a) All flowing systems in the Porcupine River drainage and the North Slope.
- b) All clear rivers in the Mackenzie River drainage, especially along the east side of the Mackenzie.
- c) Clear lakes in the Mackenzie Delta area.

7) During stream crossings, adjacent terrain disturbance should be kept to a minimum to minimize slumping. In addition, the site should be close to the tributary mouth to ensure recolonization of the disturbed area by drifting organisms, but far enough upstream to permit containment of an oil spill. The stream bed should be returned to its pre-construction condition by replacing the original substrate.

8) We have shown that very small amounts of crude oil in a running system will cause the organisms to leave the system. An oil spill near headwaters of streams, especially considering the volumes of oil involved, could conceivably cause complete removal of fauna from the whole system. It could

become a zoobenthos desert! Recovery would be very slow because of the dependency of stream fauna on recolonization from upstream areas. This again should be considered when deciding on the location of crossings.

9) The Caribou Bar Creek experience leads us to be cautious and extremely critical of any oil spill contingency plans relying primarily on floating booms in running water systems. In turbulent streams the oil is carried under and mixes well in the water column. It is difficult for us to appreciate the usefulness of any of the techniques currently in use to retain spilled oil on a stream or river.

10) The lethal effects of crude oil on a Mackenzie Delta lake indicated the sensitivity of this productive system and underlined the need for extreme care and caution concerning pipeline activity in this region. Special attention must be paid to any channel crossing bearing in mind its bank instability, especially during breakup.

11) In the Mackenzie Delta, not only does the possibility of an oil spill occurring have a high probability (bank erosion, channel shifting, ice-jams), but its effects are far-reaching. In this area, and especially in the region of productive lakes, the zoobenthos supports not only fish populations, but also large numbers of wild fowl. In addition, the vegetation is vitally important to fur-bearers such as beaver and muskrat which share the aquatic habitats with zoobenthic organisms. Quite apart from the Delta itself, oil spills are likely to have their effects extended into the estuarine and eventually oceanic zones by the enormous discharge of the Mackenzie River.

In the estuarine zone, adverse effects are likely to be maximized by the shallow and exposed bay areas having little tidal action to aid flushing and the possibility of extensive sedimentary zones becoming heavily affected by oil.

For these reasons alone, the whole Delta should be treated with extreme caution in respect to pipeline activity, with a high priority assigned to oil-spill contingency planning and procedures.

12) The addition of organic matter-rich sediments to a stream, river, or lake will reduce oxygen concentrations in the water. The depletion of oxygen by organic sediments of construction disturbances will likely have maximal effect during low discharge and low water velocity periods (i.e. July to winter).

13) Within a region of relatively uniform climate, vegetation, and geology, the area of land disturbed by construction will likely be directly related to the disturbance by siltation of aquatic systems. With increasing watershed area being disturbed by clearing, we predict greater erosion, siltation of streams and lakes, O₂ depletion, and nutrient supply. The ratio of a) land area disturbed to b) watershed area, might be a useful predictor of the impact of construction upon aquatic habitats and organisms. With increasing values of this ratio, a greater deleterious effect would be expected.

9(c) Views not verifiable from this study.

1) In the Porcupine River systems, spring and ground water areas must be avoided. The few samples collected showed zoobenthic standing crops 10 times denser than any other area. They are fish wintering areas, and we feel

their existence is essential for the re-colonization of large portions of rivers after the spring scour.

2) One stream characteristic neglected in this study was phytobenthic production. Because of the considerable standing crop which we have noticed, we feel that it must play a vital part in the dynamics of Arctic stream systems. Therefore, we recommend that extreme care be used in implementing any technique which might lower phytobenthid production (primarily turbidity).

3) Special attention should be paid to the disposition of toxic materials (e.g. engine additives, gear-oil, etc.) which might find their way accidentally or deliberately into water bodies. Sewage treatment and disposal is also likely to become a problem as increased population and urbanization follows pipeline activity.

10. Needs for Further Study

10.1 Gaps in knowledge by geographic area.

The following areas listed are not covered by the present detailed study areas, and represent regions where we are less confident in our predictions of environmental sensitivity. Any comments on environmental sensitivity of these areas is based on limited data and extrapolation from the present studies. The regions receiving more study in 1973-74 and 1974-75 are as follows:

- a) From Willowlake River to Rengleng River on the east side of the Mackenzie River,
- b) Alberta border to the region of Trout River,
- c) Richardson and British Mountains,
- d) North Slope of the Yukon, and
- e) Old Crow Flats.

We wish to emphasize that the 1972-73 studies in the regions of Fort Simpson, the Mackenzie Delta, and Old Crow do not indicate that we have an adequate understanding of the aquatic ecology of these areas. Indeed, these areas are individually quite diverse, and require broader-based research efforts to verify generalizations about each area.

10.2 Gaps in knowledge by subject matter.

Perhaps the greatest deficiency of the 1972-73 study is its inability to estimate recovery time of ecosystems disturbed by man's activities in specific areas. This deficiency is primarily a result of time constraints on the duration of the study. If experimental and control stations at Caribou Bar Creek, the Mackenzie Delta experimental lake, Martin, Harris, and Rengleng Rivers could be monitored carefully for five years, perhaps some statement could be made on the long-term effects of specific disturbances. These long term effects are, of course, the most important and critical effects. Experimental attempts to hasten recovery of disturbed ecosystems are feasible but not in the time frame of the present study.

We lack knowledge of the impact of specific toxic and deleterious substances on whole ecosystems. Many of the products and waste materials in highway and pipeline construction and operation should be experimentally tested on carefully selected and controlled ecosystems, similar to the present attempts to evaluate the impact of crude oil and increased siltation of selected streams. In addition, analytical methods will have to be developed to measure trace quantities of potentially toxic materials in water and sediments.

Studies for 1973-74 and 1974-75 are designed to obtain further knowledge of:

- 1) The physical, chemical and biological characteristics of aquatic ecosystems during the winter. Such information is essential owing to the likelihood of winter construction of pipelines;

- 2) discharge and suspended sediment data for small rivers and streams;
- 3) ecology of aquatic macrophytes and algae on disturbed and undisturbed habitats;
- 4) utilization of small, tributary streams by indigenous fish. Although general migratory movements are beginning to be described, the activities of the fish once they have entered streams are unknown;
- 5) utilization of Delta channel benthos by indigenous fish populations which are of importance to local fishermen, and the relationships between benthic and fish productivity;
- 6) zoobenthos recolonization potential and rates of recovery of disturbed streams;
- 7) ecology and biology of indicator species in streams;
- 8) specific mode of action of toxic materials on specific organisms, and determination of acute and subacute levels of toxicants that cause changes in aquatic communities. Analytical methods to determine these toxicants in water and sediments will also have to be developed;
- 9) limnology of representative lakes in the Old Crow Flats;
- 10) productivity of Mackenzie Delta lakes. These are the most productive zones in this region, they would have the most severe ecological repercussions to the whole Delta should they be detrimentally disturbed, and they are important in relation to the fish and wildlife of the area;
- 11) impact of highway crossings in continuous permafrost watersheds. A study of the Rengleng River was begun in late 1972.

10.3 Proposal for Additional Studies.

The experimental studies on the effects of crude oil and increased sedimentation on aquatic organisms were continued through 1973-74 and will be completed in 1974-75. To allow prediction of effects of rate increases of sediments, it is proposed to incrementally increase the supply of silt to a small stream and lake near Fort Simpson. These studies will be related to observations on natural rates of transport of suspended and dissolved elements from disturbed and undisturbed watersheds. More attention is being given to the chemical composition of suspended and bottom sediments.

There will be continued experimental investigation of the chemical and biological degradability of Imol S-140, a high temperature lubricant likely to be used in jet engines at compressor stations along proposed gas pipelines. Laboratory studies will continue to investigate the chemical and biological mode of action of crude oil fractions, silt, and industrial wastes on selected species of benthic invertebrates and fish.

A major necessary task is the compilation and synthesis of existing data. Much taxonomic and chemical data await evaluation. A major task in 1974-75 will be preparation of a final report to the Environmental-Social Committee.

For the longer term, it is proposed that the experimental oil spill sites of the Mackenzie Delta and northern Yukon be measured periodically to obtain information on long-term responses and recovery time.

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GLOSSARY

- Absorbance - a measure of light energy absorbed by a substance, as measured by a spectrophotometer.
- Allochthonous - arising outside of the habitat being considered; when used with "drift" means terrestrial invertebrates that have fallen in the water.
- Alluvial - pertaining to alluvium.
- Alluvium - a general term for all detrital deposits resulting from the operations of modern rivers, thus including the sediments laid down in river beds, flood plains, lakes, fans at the foot of mountain slopes, and estuaries.
- Amphipoda - an order of crustaceans commonly known as scuds or sideswimmers.
- Amylases - a group of enzymes which split starch or glycogen to maltose.
- Aliquot - subsample of known volume.
- Anion - an atom or group of atoms with a negative electric charge.
- Autochthonous - arising within the habitat being considered; when used with "drift" means the invertebrates which come from within the stream.
- Artificial substrate - a benthic sampling device which collects by colonization.
- Bathymetric - relating to measurements of depths.
- Benthos - technically, only the organisms living on or in the substrates of bottom sediments of running and standing water systems.
- phytobenthos - plant benthos
zoobenthos - animal benthos
- Boreal - from or belonging to the north; the faunal region that extends from the Polar Sea southward to near the northern boundary of the U.S., and farther south occupies a narrow strip along the Pacific Coast and the higher parts of the Sierra-Cascade, Rocky, and Alleghany Mountain ranges.
- Bivalves - refers to Pelecypoda, the class of Mollusca to which clams, oysters, scallops, cockles, mussels, etc. belong.
- Biomass - total weight of all organisms in a particular habitat or area.
- Buffer action - the action of certain solutions in opposing a change of composition, especially of hydrogen ion composition.

- Calcite - a mineral, calcium carbonate, the principle constituent of limestone.
- Catalase - enzyme which breaks down the poisonous substance, hydrogen-peroxide, formed during plant and animal metabolism, to water and oxygen. Its prosthetic group, containing iron, is same as that of haemoglobin.
- Cations - an atom or group of atoms with a positive electric charge.
- Ceratopogonidae - a family of Diptera, commonly known as "biting midges".
- Chaoboridae - a family of Diptera, commonly known as "phantom midges".
- Chironomidae - a family of Diptera, commonly known as "midges".
- Chitinase - an enzyme which hydrolyzes chitin, an important constituent of the cuticle of arthropods.
- Chlorite - a term used for a group of plathydrous silicates of aluminum, ferrous iron, and magnesium which are closely related to the micas.
- Coleoptera - an order of Insecta commonly known as "beetles".
- Colloidal state - a state of subdivision of matter in which the particle size varies from that of true 'molecular' solutions to that of coarse suspensions, the diameter of the particles lying between 10^{-7} and 10^{-5} cm. They are subject to Brownian movement and have a large amount of surface activity.
- Colorimetric analysis - analysis of a solution by spectrophotometric measurements of absorption at a certain wavelength compared with a standard solution.
- Combustion, Photochemical - refers to the oxidation of samples by means of light radiation, in our case by using mercury arc lamps.
- Conductivity - electrical conductance of a current through an aqueous solution between opposite faces of a cube of material, 1 cm edge. Reciprocal of resistivity. Values increase with increasing dissolved salt concentrations.
- Contingency plan - a plan of action to be taken in case of an emergency such as an oil line break.
- Copepoda - a subclass in the Class Crustacea; important constituents of zooplankton in fresh and marine waters.
- Crustacea - a class of the phylum Arthropoda to which belong water fleas, crayfish, lobster, shrimp, crabs, barnacles, etc.
- Cumacea - an order of Crustacea which is totally marine.

- Depth integration - a sampling procedure which samples the water column from top to bottom. Water is taken into the sampler as it descends from depth zero to maximum depth at a constant rate.
- Detritus - settleable material suspended in the water: organic detritus, from the decomposition of organisms; inorganic detritus, physically or chemically weathered minerals.
- Diffraction analyses - analyses of the internal structure of crystals by utilizing the diffraction of X-rays caused by the regular atomic lattice of the crystal.
- Diffractionometer - an instrument used in the examination of the atomic structure of matter by the diffraction of X-rays, electrons, and neutrons. It is usual to use a monochromatic beam of radiation, and to detect the diffracted beams by a suitable counting device.
- Diptera - the order of Insecta commonly known as "true flies"; includes midges, mosquitoes, and other flies.
- Discharge - rate of flow at a given instant in terms of volume per unit of time.
- Dispersants, dispersing agents - substances used to disperse and/or degrade oil spilled into the environment.
- Dissolved material - as opposed to suspended material. For our purposes, that material which will pass through a .45 μm pore-sized filter.
- Diversity - usually used to express the numbers of individuals and the numbers of different kinds of organisms; when used with an expression of quantity (e.g. abundance), it means numbers of kinds of organisms.
- Dolomite - a common rock forming mineral, $\text{CaMg}(\text{CO}_3)_2$.
- Dredge - a bottom substrate sampling device which collects by being towed on the bottom of a river or lake; e.g. sled dredge.
- Drift - organic (detrital, organisms) and inorganic material present in the moving column of water in a stream or river.
- Ecosystem - collectively, all organisms in a community plus the associated environmental factors.
- Empididae - a family of Diptera commonly known as "dance flies".
- Ephemeroptera - an order of Insecta commonly called "mayflies".
- Epiphyte - plants that are not rooted in the bottom but rather use other plants as a substrate without penetrating into them and without drawing nutrient substances from them.

Equilibrium thermodynamics - a branch of science concerned with energy changes between different states of a system defined by sets of initial and final values of macroscopic variables such as volume, temperature, pressure and concentration.

Eutrophication - the acceleration of the rate of nutrient supply (N,P) to a water body, usually resulting in increased biological growth.

Evaporite - sediments which are deposited from aqueous solution as a result of extensive or total evaporation of water. These sediments are usually salts of Na, K, Cl, F, Br, SO₄.

Floodplain - region of land adjacent to a river which is covered with river water during periods of flood.

Floodplain lake - lakes occurring within the flood plain of a large river system, formed by the inundation of basins or natural depressions.

Fluviatile - belonging to a river; produced by river action; growing or living in fresh-water rivers.

Food chain - complex species interrelationships in any community with special reference to feeding habits; more correctly called "food web"; a typical food web includes plants, herbivores, carnivores, omnivores, and detritus feeders.

Gastropoda - a class of Mollusca to which snails, slugs, limpets, whelks belong.

Glacial - pertaining to glaciers.

Grab - a bottom substrate sampling device having jaws that close with force thus removing a volume of bottom. For example: Ekman, Peterson, Ponar.

Gravimetry, (gravimetric analysis) - the chemical analysis of materials by the separation of the constituents and their estimation by weight.

Hemiptera - an order of Insecta commonly known as "true bugs"; includes water striders, back swimmers, water scorpions, giant water bugs, water boatmen, etc.

Hemolysin - a substance which disintegrates red blood cells.

Heterotrophic - the nutrition of plants and animals that are dependent on organic matter for food.

Hirudinea - a class of the phylum Annelida commonly known as "leeches".

Humic - organic acids derived from plants which, when dissolved and/or suspended in water, impart a tea color to the water.

Hydracarina - A taxonomic classification referring to water mites.

Illite - name used for a group of clay minerals abundant in argillaceous sediments. They are intermediate in composition between muscovite and montmorillonite; recent studies have shown that many are made up of interlayered mica and montmorillonite.

Indicator species - any species which is typical or peculiar to a particular kind of habitat.

Infauna - fauna consisting of burrowers in the bottom deposits of the sea.

Ion - an atom or group of atoms with an electric charge.

Ion-exchange - reversible exchange of ions between a solid and a solution.

Isolates - metabolic types of microorganisms which have been separated from heterogeneous natural populations, and kept in culture.

Isopoda - an order of Crustacea which includes pill bugs, sow bugs, woodlice.

Levee - a bank confining a stream channel or limiting areas subject to flooding, also a landing place, pier, or quay.

Life-history - a series of morphological changes and activities of an organism from time of zygote formation until death.

Lipase - enzyme which splits esters of fatty acids; e.g. true fats, into alcohol and acid.

Littoral - the shoreward region of a body of water.

Lotic - pertaining to running water habitats.

Macrophyte - large plant; usually refers to rooted, vascular plants.

Mole - a gram-molecular weight of an element or compound; to convert moles m^{-3} to gm^{-3} , multiply by the atomic mass of the element or compound; k mole is 1000 moles.

Mollusca - a phylum which includes snails, clams, chitons, squids, octopus.

Monochrometer - any device which measures light containing radiation of a single wavelength only.

Morphology - study of the form of an organism considered as a whole or in its gross aspects.

Motility - ability of an organism to move by itself.

Nematoda - a phylum which includes all the true roundworms; marine, fresh-water and terrestrial; free-living and parasitic.

Nutrient - conveying, serving as, or providing nourishment; often applied to chemicals important to the growth of lower plants.

Odonata - an order of Insecta commonly known as "damselflies" and "dragonflies".

Oligochaeta - a class in the phylum Annelida; most commonly known as "earthworms" and "aquatic earthworms".

Ostracoda - a subclass of Crustacea most commonly known as "seed shrimps".

Oxidase - enzyme which catalyses oxidation of a substrate by removal of hydrogen which combines with molecular oxygen.

Plagioclase - a mineral group, formula $(\text{Na}, \text{Ca}) \text{Al} (\text{Si}, \text{Al}) \text{Si}_2\text{O}_8$; a solid solution series from $\text{NaAlSi}_3\text{O}_8$ (albite) to $\text{CaAl}_2\text{SiO}_8$ (anorthite). One of the commonest rock forming minerals.

Pelecypoda - a class of Mollusca to which clams, oysters, scallops, cockles, mussels belong.

Periphyton - entire assemblage of sessile plants (mostly microscopic) on submerged substrates in aquatic environments.

pH - activity of hydrogen ions in solution; the normal values range from pH 0 to 14, pH 7.0 being neutral, at which point the activity of hydrogen ions and hydroxyl ions are equal; values below pH 7.0 are acid, above pH 7.0 are alkaline.

Photosynthesis - complex of processes involved in the formation of carbohydrates from carbon dioxide and water in living plants in the presence of light and chlorophyll.

Phytobenthos - see Benthos.

Phytoplankton - collectively, all those microscopic plants suspended in the water of aquatic habitats.

Plecoptera - an order of Insecta commonly known as "stoneflies".

Polychaeta - a class of the phylum Annelida (true worms) of which most members are marine.

Primary productivity - total quantity of green plant protoplasm produced per unit time in a specified habitat. Operationally, this is often expressed as the amount of carbon taken up (or O_2 released) by photosynthetic organisms per unit volume or area over a stated time period.

Production - total quantity of living protoplasm produced per population unit in a specified habitat.

Productivity - inherent capacity of an environmental unit to support organisms; rate of utilization of energy or formation of protoplasm by one or more organisms.

- Profundal - the deep region of a body of water, usually below the light-controlled limit of plant growth.
- Proteinase - (peptidase) - an enzyme splitting peptides, and in many cases proteins, by attacking certain peptide links.
- Psychodidae - a family of Diptera commonly known as "moth flies".
- Quartz - a mineral, SiO_2 .
- Rate of transport - rate of flow of material expressed in terms of mass per unit of time.
- Refugium - isolated unmodified locality which is surrounded by an area drastically modified by geological, climatic, or other physical alteration; often a center for relict species.
- Rhagionidae - a family of Diptera commonly known as "snipe flies".
- Secchi visibility - a field measurement of the transparency of the water column, performed by lowering a black and white painted disc into the water until it cannot be seen.
- Sediment - fractionated - the composition of the sediment is subdivided on the basis of the size of particles; i.e. into sand (2mm-50 microns), silt (50 microns-2 microns), and clay (<2 microns).
- suspended - particulate material in the water.
- Seston - suspended inorganic and organic material in water.
- Simuliidae - a family of Diptera commonly known as "black flies".
- Solifluction - slow movement of rock and soil down slope solely under the influence of gravity; on slopes subject to frost action either in areas of permafrost or in nival areas subject to freezing and thawing.
- Soxhlet apparatus - a laboratory apparatus for the continuous extraction of a solid substance with a solvent.
- Specific conductance - the reciprocal of resistance to the passage of an electric current through a solution.
- Spectrophotometer - instrument for measuring intensity of each colour or wavelength present in a solution.
- Spectroscopy - atomic absorption - the basis of the method is the measurement of the light absorbed at the wavelength of a resonance line by the unexcited atoms of the element.
- X-ray fluorescence - involves the excitation of fluorescent radiation within a sample by the polychromatic radiation from the X-ray tube.

Standing crop - total number or weight of living organisms momentarily present in an environmental unit.

Substrate - the ground or any other solid object to which an animal may be attached, on which it moves about, or with which it is otherwise associated; commonly refers to bottoms of streams, rivers, and lakes.

Supercooling - cooled below normal boiling or freezing point without a change of phase.

Surber sampler - a device used to sample one square foot of the bottom of shallow streams and rivers.

Taxon - any formal taxonomic (relating to classification) unit of organisms; for example, species, genus, family, order.

Taxonomy - scientific naming of organisms and their classification with reference to their precise position in the animal or plant kingdom; the theoretical study of classification, including principles, procedures, and rules.

Tipulidae - a family of Diptera commonly known as "crane flies".

Titration - the addition of a solution from a graduated vessel to a known volume of a second solution, until a chemical reaction between the two is just completed. A knowledge of the volume of liquid added and the molarity of one of the solutions enables that of the other to be calculated.

Trace elements - elements usually found at very low concentrations in water; typically $<10^{-5}$ moles/l.

Trichoptera - an order of Insecta commonly known as "caddis flies".

Tundra - treeless areas of high latitudes and altitudes; characterized by growths of low herbs, lichens, mosses, and grasses.

Turbidity - a measure of the amount of material suspended in the water; opacity.

Zoobenthos - see Benthos.

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